ELEMENTS
OF
PLANT
PROTECTION

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by ——————— L. L. PYENSON

CFTRI-MYSORE
2015
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ELEMENTS OF
PLANT PROTECTION

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Emily B. Steffens

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FOREWORD

The early local history of America is filled with the struggles of the settlers to protect their crops against predatory animals and birds. An interesting example is the stories of the fight of the settlers to destroy the thousands of pigeons that pulled out the young corn just as it was nicely started or ruined the crop after it was in the ear.

While some degree of plant protection has always been necessary, it has not been until comparatively recently that the farmer has had to wage almost constant warfare against insects and disease to prevent the destruction of nearly every crop he grows. Men still living well remember when it was possible to raise good apples without spraying, when there were few potato bugs, and when potatoes did not blight. Today just to list the diseases, weeds, predatory creatures, and insects destructive to plants, that were unknown to our forefathers, would fill pages.

The older agriculture grows, the more its enemies increase. Were it not for the farmer's constant fight to protect his plants, and for the constant research for new controls and equipment, we would all soon starve.

This volume has been prepared as a text and source book for students in vocational agricultural classes in high schools, in technical institutes, and in the early years of agricultural colleges. The instructional materials will provide an excellent background for students and farmers alike concerning the enemies that attack our useful plants and the remedies and equipment that have been developed and used to control them. Instructors in the general field of plant protection will find the volume appropriate for the organization and teaching practices in the various types of classes in schools, institutes, and colleges. The author's extensive experience in teaching has enabled him to develop practical materials that have been thoroughly tested in the classrooms, in the laboratory, in the greenhouse, and in the field. The student, the farmer, and the lover of Nature will find Plant Protection interesting and informative reading and a valuable reference.

Someone has said that the most important purpose of education should be to put one in touch with his environment. Surely, no one can be truly educated unless he has some knowledge of the great world of Nature around him and of the constant fight for survival between man and his natural enemies. No one can read *Plant Protection* without having a better understanding of this constant warfare by man to protect his food supply.

The Editors

PREFACE

This book is written for our future agriculturists and horticulturists. It needs no justification, for it is as basic to proper plant protection as elementary botany is to horticulture and as mathematics is to engineering. Twelve years of teaching courses in plant protection to students in agriculture and horticulture have convinced me that unless there is first a basic understanding of the underlying elements, the field work on identification and control is superficial and does not prepare young people to adapt themselves readily to changing conditions, to foresee and recognize new problems promptly, or to deal with them intelligently.

The book brings together information on all plant pests such as insects, disease-producing organisms, rodents, birds, and weeds. It discusses their nature and control practices in a simple, concise, and "down to earth" fashion. Technical expressions and purely academic material have been eliminated wherever possible; however, no science is simple, and certain technical terms or expressions must be understood in order to comprehend information and developments in a given field. Agricultural production has become a highly technical profession, and much more than manual dexterity and a strong back is required to make a success in it.

Scientific names are included so that the instructors may be sure of the identity of the organisms involved. Students need not be held responsible for them.

Parrot-like acquisition of information is not education—students must learn to interpret and use this information to their advantage; they must acquire the "know why" as well as the "know how." The questions at the end of each chapter are presented to stimulate logical reasoning and discussion on the part of the students. Answers to many of the questions will not be found in the text, nor are there any clear-cut answers in some cases, but the students should be encouraged to reason from the known facts. For more detailed information the references cited in back of this book and experiment-station literature should be consulted.

The material is adaptable for introductory one-semester courses in economic entomology, plant pathology, or weed control; or for one continuous course covering all three subjects. The subject matter is organized so that certain parts may be left out if the nature or length of the course so dictates. The last three chapters on application equipment and its use are common to all the phases of plant protection.

The most satisfactory method of subject-matter presentation is to give students definite assignments in the book and to utilize the class periods for discussions based on the questions at the end of each chapter and others that the instructor may think of. Laboratory studies should supplement the textbook assignments. Preserved or living specimens and spray chemicals and application equipment should be employed for actual study. Kodachrome transparencies of insects, rodents, plant diseases, weeds, crop damage, and control practices may also be used to advantage in supplementing the illustrations.

It is beyond the scope of the book to include specific information on many plant pests or troubles. Those included are mainly for the purpose of illustrating types. The subject matter lays the groundwork for a subsequent field-laboratory course on the identification and control of specific pests common to the student's own region. Although it is intended mainly for students, this book may also serve all those in agricultural pursuits as a helpful basic reference work.

I am greatly indebted to innumerable research workers and writers for the vast amount of information from which much of the material was gleaned. In the preparation of the manuscript I have profited from the suggestions and criticisms of the editors and of several authorities who read portions of it. Mr. Harvey Barke and Dr. Lawrence Southwick have offered me some helpful suggestions. Mrs. Emily B. Steffens, a former student at the Institute, deserves much credit for the many excellent line drawings. Grateful acknowledgment for the illustrations or of their source is made in the legends.

Mrs. Doris Ramaley, Mrs. Margaret Geldof, and Miss Marie Butto gave valuable help in typing the manuscript; and my wife, Estelle Pyenson, was an invaluable aid and comfort throughout its preparation.

Louis Pyenson

Farmingdale, New York
August, 1951

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INTRODUCTION

THE PROBLEMS OF PLANT PROTECTION

The cultivated plant is the battleground where the interests of man meet and clash with those of innumerable organisms and phenomena of Nature. Rodents may consume the plants, birds may eat their fruits, insects may drain their life juices, bacteria and fungi may invade their tissues, droughts may wither them, and weeds may crowd them out, often in spite of man's best efforts.

It is a battle of blind instincts and numbers against the inventive genius of man. Animals when hungry go in search of food, but man has learned how to grow plants for food for himself and his domestic animals. He has taken the most tasty, nourishing, or beautiful of these plants and learned how to reproduce, grow, and improve them, not in the manner of Nature, in scattered units among thousands of other types of competing plants, but as millions upon millions of identical plants covering, in some cases, hundreds of acres. He has made it possible for a few to supply food for the many. This is agriculture, modern and intensive agriculture, which has enabled man to increase tremendously in population, to supply huge non-agricultural populations concentrated in large cities, and to advance his standard of living far beyond that of his cave-man days.

But all this is contrary to Nature's way of life, this hurrying and shaping plant evolution to suit man's own needs, this concentrating of single species of plants on the one hand, and of man and his domestic animals on the other. Nature works in centuries, but man in a period of 50 years has speeded up or by-passed natural evolution and has produced changes in North America that have led to the creation of many grave problems of plant protection. Our agricultural economy has reached such a stage that, if insect-, disease-, rodent-, and weed-control measures for our crops were suddenly stopped in the United States for a few years only, starvation would stalk the country, and huge segments of our population would be wiped out by the ensuing famine. Our highly developed agricultural and horticultural production has been made possible only by parallel developments in our knowledge of the various factors causing crop losses, and of ways of dealing with many of them quickly and effectively.

THE ECONOMIC IMPORTANCE OF PLANT PESTS

Plant pests may be grouped in general as insects, plant diseases, weeds, rodents, and birds. The relative importance of these groups is illustrated in Fig.1. These estimates of damage tend to be conservative and should serve to emphasize the importance of plant protection not only to the grower

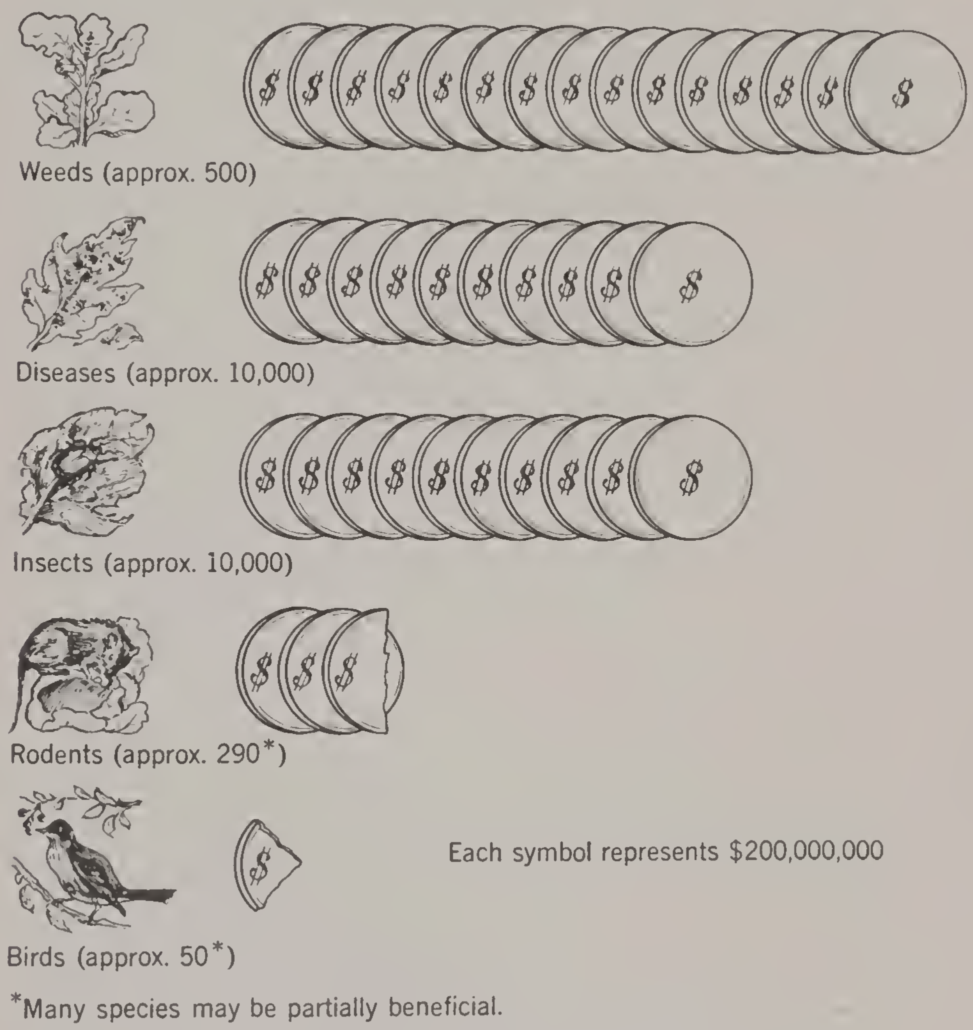

FIG. 1. Estimated yearly losses from crop pests in the United States (based on estimates from several sources).

but to the consumer to whom these losses are passed on in the form of insufficient supplies and higher costs.

INSECTS AND PLANT DISEASES. Insects are the most numerous species of organism in the animal kingdom, averaging about 40,000 individuals to the acre. Approximately 80,000 species have been identified so far in North America, and it is estimated that 2,000,000,000 more exist on this earth. Some 10,000 of these 80,000 species are known to be harmful to agriculture, with 60 of the most important ones alone costing agriculture approximately $ 1,600,000,000 a year. To these figures may be added some 10,000 infectious plant diseases of known economic importance out of a total of about 25,000; 500 of these are leading diseases of major crops, costing about $ 2,000,000,000 a year. Non-infectious plant diseases caused by nutritional or environmental conditions undoubtedly add greatly to this sum. One should keep in mind, however, that the figures are annual averages and that damage tends to vary greatly from year to year, from state to state, and even from field to field. Even though the American grower puts more than $ 100,000,000 worth of sprays and dusts on his crops annually, controls for many pests are not adequate or not practical, and huge losses are still suffered from pests for which control recommendations exist. These figures present a challenge to every grower to improve his methods of pest control.

WEEDS. These persistent and unwanted plants are a major problem of every plant grower; their control takes up the bulk of the time and work spent in growing many crops. Although their actual number is small compared to that of insects or diseases, weeds make up in numbers of a kind and in persistence what they lack in variety. Many crops would never mature without weed control, and at best their presence stunts plants and reduces crop yields.

RODENTS. Rodents are a major, year-round cause of damage to crops and trees in some agricultural areas of the country. In some areas their tunneling leads to serious soil-erosion problems. When they occupy non-agricultural lands, or when they are few in number, they are considered of value in maintaining normal populations among the animal species of a region.

BIRDS. A number of our birds play the role of Dr. Jekyll and Mr. Hyde. At certain times of the year they may be highly beneficial, feeding mainly on insects, and at other times their tastes turn to fruits, vegetables, or grains with subsequent great crop losses. Very few of our birds are wholly bad, and therefore the farmer faces the problem of discriminate bird control, since their value may overbalance their destructiveness. In most cases control measures are required only locally and at certain seasons of the year.

The figure on the annual bird damage is the author's own estimate; no available figures could be found. Some figures on local losses were found, e.g., from crows, an estimated $7,500,000 annual loss to Oklahoma farmers.

THE RISE OF THE PLANT PROTECTION PROBLEM

This picture of costly crop losses due to pests is rather gloomy, but we must first understand how and why this problem has snowballed into its present state before we can comprehend the situation adequately.

Our fathers or grandfathers have often remarked that fine, clean crops were produced some 50 years ago without any need for sprays or spraying, and that plant pests did not trouble crops in those days. This is only partly true: many farmers even then had more than their share of insect and disease troubles.

Looking back at the records of pest troubles in the day of the horse and buggy we can find many records of destructive insect and disease outbreaks. In 1867 the Ohio Horticulture Society in its first report stated that many apples of that year's crop were defective and wormy and that the currant worm had invaded the state. During the 1870's the plum curculio was mentioned many times as one of the worst pests of plums, cherries, apples, and peaches. Some growers even gave up plum growing because of this pest. The codling moth was first mentioned by name in 1868. In 1869 the Colorado potato beetle in its eastward march had invaded Evanston, Ill. Cankerworms, aphids, apple maggot, squash vine borer, rose chafer, and grape phylloxera were also noted in reports of that time. By 1893 the San Jose scale had reached Ohio, and its subsequent damage was so great that many growers believed that fruit growing was doomed. From 1892 to 1916 bark beetles, grape berry moth, woolly apple aphid, and other apple aphids became pests on crops.

The early history of disease appearance closely parallels that of insect troubles. As soon as a crop was fairly well established, disease promptly appeared. About 1850 apples, peaches, and thousands of acres of grapes were planted in Ohio. As soon as fruit production started, disease epidemics appeared. Mildew became so destructive that by 1869 thousands of acres of grapes in southern Ohio were being abandoned. The grape industry suffered great losses yearly from black rot until the grape industry moved north to the Lake Erie region. Apple scab was very serious, causing complete crop losses in many sections. Bitter rot was also prevalent. During the 1867-1885 period, crop after crop was lost and hundreds of orchards and vineyards were abandoned. Only the discovery of Bordeaux mixture as a fungicide and its use beginning about 1885 made fruit growing possible in some areas.

THE CAUSES OF OUR PLANT PEST PROBLEMS

1. NATURE'S METHODS VERSUS AGRICULTURAL PRACTICES. Our modern type of agriculture has helped create these plant troubles; of this there can be no doubt. Experience has shown us that the more highly developed and intensive agriculture becomes in any country, the more complicated are its problems, and the more plant troubles arise. This is not unexpected, since man through agricultural practices has been able to create great radical changes in the biological world in a relatively short period of evolutionary time. This in turn has upset Nature's intricate system of checks, counterchecks, and succession of populations. In this system no organism, plant or animal, is allowed to gain complete domination indefinitely; it is sooner or later checked by overcrowding, lack of food, climatic factors, disease, or its natural enemies, and other organisms may gain a period of ascendency, only in turn to be replaced by still others. These periods of abundance and scarcity of animal populations may appear at regular or irregular intervals and are referred to as cycles. Cycles in animals may run anywhere from a few to 50 or more years apart. As examples, field mice have 3- to 5-year cycles, squirrels 5- to 6-year cycles, tent caterpillars about 10-year cycles, and cankerworms about 5-year cycles.

Nature tends to scatter plant species, making survival difficult for their disease and animal pests; agriculture, on the other hand, tends to concentrate millions of a single species, bred usually for their nutritious value, in definite areas year after year. This is an open invitation for food-hungry organisms to attack, destroy, and multiply. Acre upon acre of weedless corn, potatoes, or apples offer the optimum conditions for the rapid multiplication and spread of any organism that finds one of these crops a suitable host.

2. INCREASE IN OLD PESTS. Many of our old pests have increased greatly in population. This has happened in spite of constantly improving methods of combating them. The New York State Experiment Station reported that codling moth populations reached an all-time peak in 1944 in the eastern United States. Unsprayed plots of apples in 1924 showed 10 per cent worm attacks, whereas in 1944 they showed 30 per cent worm attacks. Among the factors given as probably contributing to this build-up were: (1) the heavy plantings of apples tend to concentrate codling moth and cause rapid increase in numbers during favorable seasons; (2) the popularity of the McIntosh has kept orchards planted largely to a variety most attractive to this pest; (3) the McIntosh is an annual bearer and so furnishes the insect with a good food supply every year.

3. INCREASE IN FORMERLY OBSCURE PESTS. Many obscure insects, diseases, and animal pests, at one time restricted in area of spread by the presence of their wild weed hosts, have turned to or have adapted themselves to related cultivated crops and have spread wherever these crops are grown. Fire blight, once a disease of the native wild crab apples in the Hudson Valley transferred to the imported apple and has become a serious pest on them and pears as well throughout the United States. The Colorado potato beetle, once a pest of wild solanaceous plants, and the Mexican bean beetle, once a pest of wild leguminous plants in the southwestern United States, transferred to their cultivated relatives, the potato and bean respectively, and are now pests in nearly all areas where these crops are grown.

4. IMPORTED PESTS. Many new pests, both animal and plant, have been brought in from other countries mainly with plant materials for food or cultivation. The European corn borer arrived in a shipment of broom corn from Europe about

1909; the Japanese beetle in soil around the roots of ornamentals from the Orient about 1916; the Dutch elm disease on imported elm logs from Europe about 1930; and the chestnut blight on imported nursery stock from China about 1909. Both the English sparrow (1850) and the gypsy moth (1869) were intentionally imported for supposedly useful purposes before their destructiveness became apparent. Johnson-grass was introduced as a forage plant from Turkey about 1830 and has since spread to most southern agricultural areas as a troublesome weed. These imported pests tend to flourish and spread rapidly, if the climate is favorable, because most of their natural enemies are left behind.

5. NEW STRAINS AND RACES OF INSECTS AND PLANT DISEASES. In recent years new strains or races of insects and plant disease-producing organisms have developed. This has lead to a constant changing of our plant-protection problems. It has been definitely established that the continuous use of DDT on houseflies has led to the development of resistant strains that retain this resistance through a number of generations. There is evidence that greenhouse red spider has developed a strain resistant to parathion where it is used continuously. Continuous use of chlordane or lindane also makes for resistant housefly strains. In some areas of Southern California there is a strain of the black scale on citrus that is resistant to hydrocyanic acid fumigation.

Through natural mutation and hybridization, new parasitic races of plant disease-producing organisms have originated, making plants that were formerly resistant or bred for resistance to a disease possible victims of the new strain. There are many records of supposedly resistant varieties being nearly wiped out by a disease epidemic or rendered useless for further crop production by a new physiological strain of the disease organism that has appeared on the scene. A new wheat variety, Ceres, was resistant to stem rust for 10 years, but has become completely susceptible to it since 1935 because of the virulence of stem rust race 56 to it. More than 200 races of this disease are known. Many disease-producing bacteria and viruses as well as fungi comprise races differing in virulence to different varieties of the same plant species. Thus we live under a constant menace that nature will make new combinations of genes for virulence to jeopardize plant varieties that now seem highly resistant under a wide range of conditions.

6. SOLUTION OF ONE PROBLEM OFTEN CREATES OTHERS. Plant varieties bred for resistance to one disease may often be very susceptible to others. Often major pests are created out of minor ones when new varieties of crop plants are grown. In the spring wheat area there has been a constant change in disease problems. The wheat varieties Preston, Haynes Bluestem, and Glyndon Fife, grown 35 years ago, were resistant to scab, loose smut, and leaf rust but were susceptible to stem rust and stinking smut. When the stem rust-resistant Marquis variety replaced the older varieties, scab became a major problem; and when the farmers turned to durum wheats, root rots and ergot became problems. When the rust-resistant varieties Kota and Ceres replaced the durums, stinking smut, loose smut, and leaf rust again became troublesome. When Ceres was ruined by a new strain of stem rust in 1935, it was replaced by Thatcher, which again created an orange leaf rust and scab problem.

The recent apparent solution to the codling moth problem by the use of DDT sprays has made major pests out of red mites and mealy bugs, which DDT does not control but whose parasites and predators it evidently does control.

Some newer varieties of plants may be more susceptible to certain pests or diseases unless bred specifically for resistance. Good examples are the old scab-resistant Baldwin apple and the newer scab-susceptible McIntosh apple.

7. INCREASE IN NUTRITIONAL DISORDERS OF PLANTS. There has apparently been a great increase in nutritional disorders of plants in recent years, or we have become more aware of them. This may be partly due to our agricultural practices of intensive cropping, to lack of crop rotation, and to soil exhaustion.

8. WILD LIFE DESTROYED. With the occupation and elimination of wild areas much of the beneficial wild life has been destroyed or driven away. Insectivorous birds, predatory birds, insectivorous animals, and animal predators are disappearing, leaving to flourish and multiply pests such as mice, rabbits, and insects that are adapted to live in close proximity to man.

9. CHEMICAL CONTROL OF INSECTS HARMFUL TO NATURAL PREDATORS AND PARASITES. We have become more and more dependent on artificial chemical control to check our crop pests, and this in turn is harmful to their

natural enemies, which under normal conditions help keep them in control. This destruction of beneficial populations makes it necessary to continue chemical control once we commit ourselves to it or else to suffer huge losses.

10. CONSUMERS NOW QUALITY CONSCIOUS. Another grower's problem is that the consumers are now more quality conscious than ever before. Years ago no one heard of graded fruit or vegetables—people expected to get the bad with the good, and a few cull or wormy apples were not considered just cause for turning down a possible purchase. Under present conditions only the best grades get top prices, and culls are discarded or sold at a loss. It does not pay the farmer to grow anything but the best grades of produce. Through economic necessity growers have been made quality conscious, and they now must make special efforts to control pests to which they had formerly resigned themselves.

FACING THE PLANT-PROTECTION PROBLEM

Whenever plants are grown, whether they are flowers or shrubs for beauty, trees for shade or lumber, or fruits, vegetables, or grains for food, a constant struggle must be waged to insure the growth and production of these plants. The battle begins with the moment that seeds are placed in the soil and ends only with the cessation of the useful life of the plants or their products. No crop would do well if left to fend for itself for long.

To grow a crop successfully from beginning to end requires not only knowledge of the best cultural conditions but also an awareness of all the potential dangers that may beset plants and of ways to avoid the dangers. The successful farmer today must know what pests to expect on his crops, when and under what conditions their attacks will take place, the weak points in the pests' stages of development, the methods and materials best fitted to combat them, and finally the most effective and efficient equipment for applying control measures.

Individually and collectively we can no longer sit back in this new era of scientific development and expect to live by the pest-control standards set by our fathers. Those growers who are to do outstanding jobs of pest control must know how to use highly specialized information in order to put modern methods to work on their farms. The best farmers will be as scientifically trained and as well equipped with mechanical and chemical tools as most successful industrial leaders. Farming is rapidly passing from an art to a highly technical and mechanized operation.

WHERE TO OBTAIN INFORMATION AND HELP. Quite often trouble appears, with which the grower is not able to cope. He must then know where to get the services of agricultural scientists to help him solve his problem or problems. There are various agricultural agencies established to serve the grower's needs. Such agencies are county agricultural or farm bureau agents, state agricultural schools and colleges, state experiment stations, and the United States Department of Agriculture in Washington. Generally their own local state or county agricultural agency will offer growers the quickest help and cooperation with their problems.

KEEPING UP WITH LATEST DEVELOPMENTS. A part of every grower's spare time should be allocated to gathering information about his crops. This may be obtained through personal visits to agricultural institutions, attending lectures, and reading relevant extension literature. Every grower should be on the mailing lists of his local and Federal agricultural agencies and should subscribe to one or more agricultural periodicals to help him keep up with the latest developments, recommendations, and warnings.

It should be sobering to realize that man by his own efforts has never yet been able to eradicate one single insect species, plant disease, or weed from this earth.

QUESTIONS FOR THOUGHT AND DISCUSSION

1. Explain the statement that "agriculture is not natural."
2. Are plants helpless as far as fighting their own enemies is concerned?
3. How has man by-passed natural evolution?
4. The statement in the text, that starvation for us would result after only a few years if all pest-control measures were stopped, may sound fantastic. Is there any evidence to substantiate this statement?
5. Our highly developed state of agricultural and horticultural production was made possible only by parallel de-

velopments in pest control. Explain.

6. Why does increased agricultural production lead to more bugs and blights?

7. Under what conditions may it not be worth while to control the pests of a crop?

8. Would it be to our benefit to destroy all rodents and insects if we could?

9. Why do cultivated crops need care whereas weeds flourish without care?

10. Why can we give only estimates of annual crop losses from pests?

11. Is a 3 per cent average annual loss in a $100,000,000 crop as important as a 12 per cent average annual loss in a $25,000,000 crop from an individual grower's standpoint? From a national standpoint?

12. Why is it misleading to say that crops were not troubled by pests in our grandfathers' time?

13. Some of our pests have increased greatly in numbers in spite of improved methods of control. Give some reasons why this has occurred.

14. Is it correct to say that the populations of organisms in Nature are in a state of balance with each other?

15. What conditions would favor an obscure insect or plant disease in becoming a destructive plant pest?

16. Why is it generally true that an introduced pest is never as harmful in its native country as in its new habitat?

17. Is there any assurance that once an insect or a disease has been controlled or conquered by chemicals or by resistant plant varieties it will stay conquered? Present evidence.

18. Why have nutritional disorders of plants come to the forefront in recent years?

19. Is there any truth to the claim that natural organic fertilizers make plants resistant to pests whereas synthetic inorganic fertilizers tend to make plants susceptible to pests?

20. Does any relationship exist between wildlife abundance and pest abundance? Explain.

21. In what ways have the grading laws for fruits and vegetables helped in the promotion of pest control?

22. What are some of the uncertain factors in plant production?

23. Can you cite any examples of complete local or world eradication of an animal species? What made eradication possible in such cases?

24. Is it necessary for a grower to be better versed in plant troubles and their preventives now than in former years? Explain.

Chapter 1

THE EXTERNAL AND INTERNAL STRUCTURE OF INSECTS

Before we an deal intelligently and successfully with any plant pest we must learn not only about its appearance but also something of its activities—the strong and weak points in its life cycle, especially its vulnerable periods, since during these our attacks will be most effective.

Insects show a remarkable range of adaptability to various environments. Some are aquatic, but most are terestrial. They are found in every part of this earth where life can exist, from the arctic regions to the tropics. Their diet includes almost every kind of living and dead organic material from the tissues of plants to the blood of mammals. No part of a plant is safe from their attack, for they can riddle internally as well as suck and chew externally.

GENERAL BODY FEATURES OF INSECTS

All insects are covered by an outer skeleton, a shell-like tissue known as chitin, colorless and transparent in its pure state, as in the wings of a fly. Periodically, during their immature stages, insects wriggle out of their chitinous skeletons and form new ones, during what is known as a molt. The chitin has properties similar to those of cellulose, the chief constituent of cotton and nylon.

This chitin in addition to supporting and protecting the internal organs of an insect also prevents excessive loss of moisture from the body. Chitin is resistant to the action of some of the strongest chemicals. This helps complicate the problem of insect control and may explain the ineffectiveness of many materials.

As an aid in escaping their enemies many insects have natural background-color patterns and chitinous or hair-like growths or protuberances. These natural colors may be acquired in three possible ways: the chitin may be transparent and the color may be that of the blood or of the internal organs, as in many caterpillars; the chitin may have colored scales or hairs growing on it, producing characteristic patterns, as in most moths and butterflies; or the chitin may be impregnated with pigments, as in many beetles.

Encased in this natural coat of armor, a hard-bodied insect still must have ample freedom of movement. This is possible because the insect's body is divided into a series of segments, one behind the other, with the chitin remaining soft and pliable at each point of segmentation in the abdomen and at the joints in the legs and wings. Many insects, chiefly during their early development, have only a soft, somewhat elastic chitin covering their bodies.

The Divisions of the Body

The body of an insect as represented by the grasshopper (Fig. 2) and the beetle (Fig. 3) is divided into three well-defined regions—the head, the thorax, and the abdomen. The head is a sharply defined region bearing most of the sensory organs of the insect. The thorax is the heaviest portion of the body and bears the legs and the wings when present. The abdomen, which begins behind the point of attachment of the hind pair of legs, is generally the longest and the most segmented part of an insect's body.

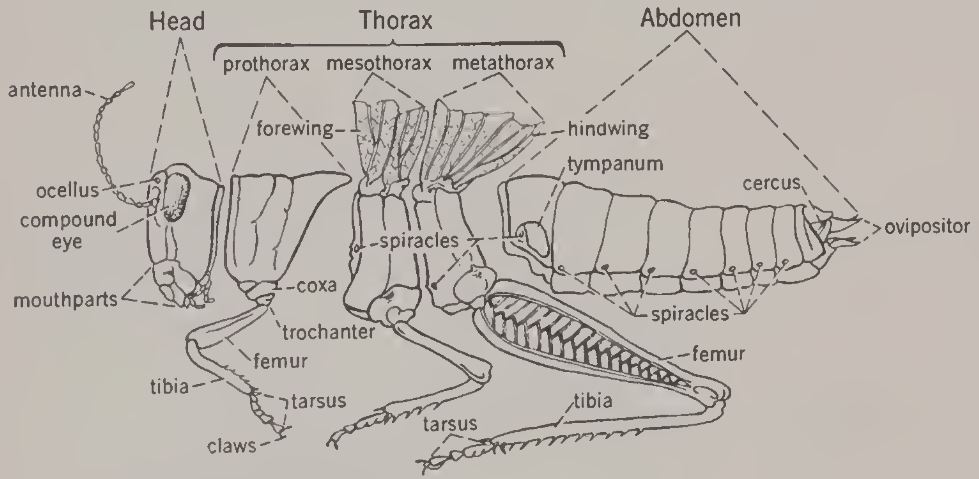

FIG. 2. An exploded drawing of a grasshopper showing the main body regions and their appendages (redrawn from Metcalf and Flint, Fundamentals of Insect Life).

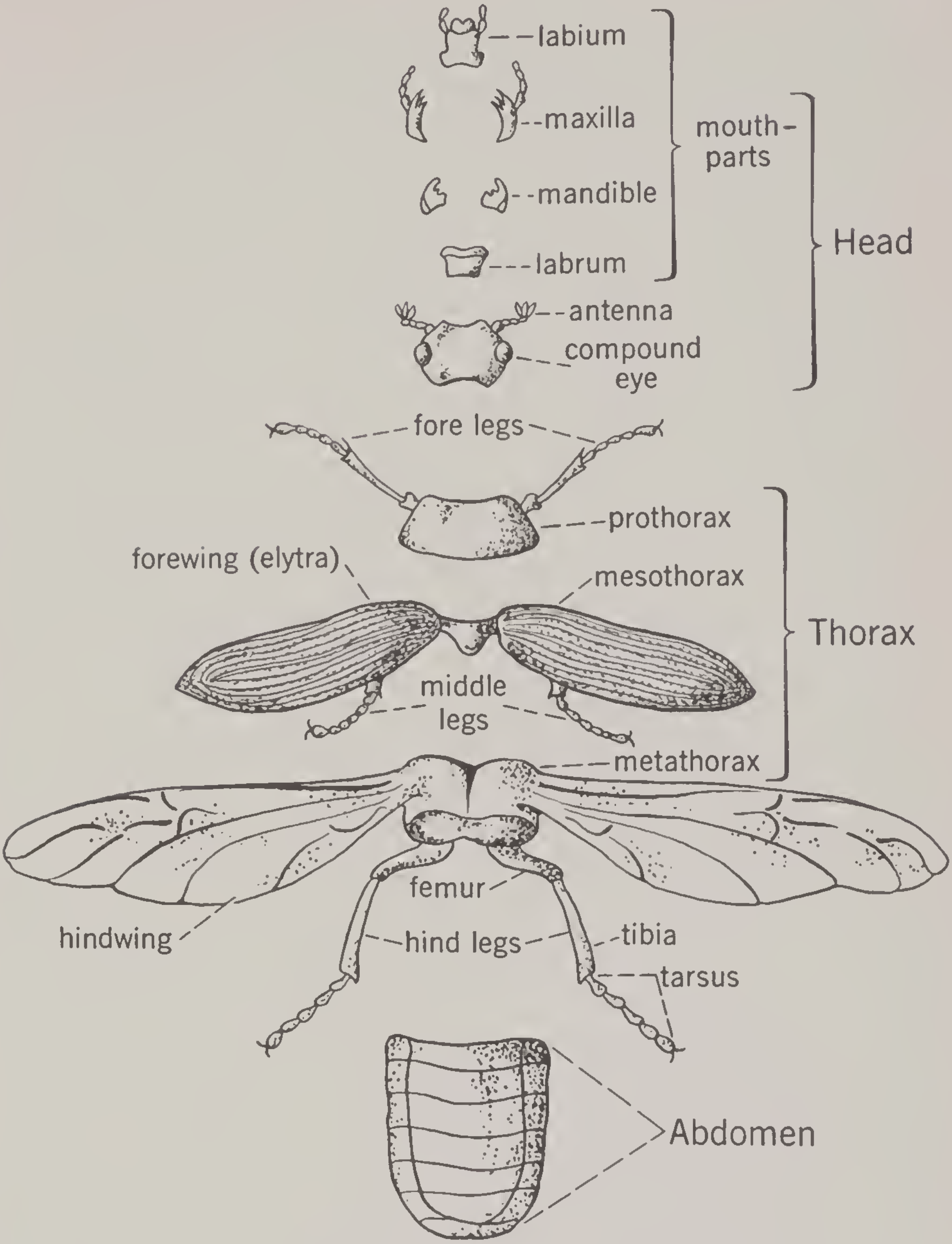

FIG. 3. An exploded drawing of a beetle showing its external structures.

The Appendages of the Head

Every insect has a pair of antennae located on its head. These antennae vary greatly in length, shape, and number of segments in different species of insects. They are sensory, but their exact function also tends to differ in different insect species. It is generally agreed that where they are long and flexible, as in grasshoppers, they function as sensitive feelers for sounding out the environment. In flies they have been found to have the sense of smell, and in male mosquitoes they act as hearing organs vibrating to the pitch of the female mosquito. In other insects they may be used to find food, locate mates, or, as in ants, for communication.

Nearly all adult insects and many immature ones have two compound eyes composed of hundreds of visual units called facets. Because the eyes bulge, insects can see in all directions at once without turning their heads or bodies. The extreme difficulty of approaching an adult insect from any direction without disturbing it indicates its excellent vision in all directions. These compound eyes vary greatly in size and shape in different insect species. In addition to the two compound eyes most adult and immature insects have tiny, bubble-like visual units called simple eyes or ocelli on their heads. The usual number of ocelli is three in adult insects and up to six pairs in some immature forms such as caterpillars which do not possess compound eyes. The visual functions of ocelli in relation to that of the compound eyes are not definitely known, but when present alone in caterpillars they serve all the visual functions that those insects require.

The remaining structures on the head are the mouth parts, which vary greatly in structure and function. The structure of the mouth parts helps tell us about the feeding habits of the insects, and these in turn are closely related to control. Mouth parts are discussed in detail later in this chapter.

The Thorax

Situated immediately behind the head is the thorax of an insect. Typically, it is divided into three rather distinct segments, each segment bearing a pair of legs (Figs. 2 and 3). The first thoracid segment, the prothorax, never bears wings, but in most adult insects the second or mesothorax, and the third or metathorax each bears a pair of wings. The three pairs of legs are generally alike in most insects, but, in some, one pair or another are specialized for a definite function, such as the hind legs of the grasshopper for jumping, the front legs of a mole cricket for digging and cutting roots, the hind legs of the honey bee for collecting pollen, and the front legs of the praying mantis for catching and holding its prey.

The leg joints (Fig. 2) consist of the coxa, which fits into the body like a ball and socket joint; the trochanter, a small, inconspicuous segment; the femur, the heaviest portion of the leg; the tibia, the slimmest and longest segment, sometimes armed with spines; and the tarsus, the foot of the insect, made up of as many as five segments. To help in clinging, the last tarsal segment generally bears a pair of claws and a pad-like structure called the pulvillus, which in flies bears tiny, secretory hairs with a mucilaginous substance to aid in clinging to ceilings and walls.

The Wings

Only adult insects have functional wings to carry them quickly from place to place. Most mature insects have two pairs of wings, some have only one pair, and a number are wingless throughout life. The wings vary greatly in size, shape, and structure not only in different species but also between the forewings and hindwings in the same species. The wings are chitinous outgrowths from the body, bearing thickened, hollow areas called veins in characteristic patterns referred to as venation. This venation remains constant for the same species and is of importance in identifying insects, as in some cases a slight difference in the venation is apparently all that separates two very similar-looking species of insects.

In many insects the forewings have lost their flying function and serve only as hard, protective covers, called elytra, for the membranous hindwings (Fig. 3). In beetles the elytra are held out of the way of the hindwings, which fold underneath them when not in use. All beetles have elytra. The group of insects that are known as true bugs have forewings known as the hemelytra. As the name implies, their basal ends are thickened, whereas their distal ends are membranous. The wings of moths and butterflies are generally covered with scales which, when viewed under the microscope, look like shingles on a roof—arranged in rows and overlapping. True flies have only one pair of wings; the second pair is represented by a pair of slender, clubbed appendages called halteres.

The Abdomen

The segments that form the abdomen of insects are generally similar to each other but tend to taper near the end, where modifications occur in many forms.

In grasshoppers, hearing organs called the tympana are present on each side of the first lateral segment of the abdomen under the base of the hingwings. Male cicadas have a pair of "vocal" organs similarly located. Paired small openings on the lateral sides of each of the abdominal segments except the last one or two are the openings of the breathing organs and are referred to as spiracles. One or two pairs are also found on some of the thoracic segments but never on the head. Thus we see that insects have many "noses," and even if some cease functioning the rest are ample to take care of the insects' needs. It is through these spiracles that many insecticides enter insects' bodies and kill them. Many insects have the power to open or close these spiracles, and this is thought to be one of the causes of the great variation in lethal effect of toxic gases on insects.

True legs are never present on an insect's abdomen, but, in some immature forms such as caterpillars, paired, unsegmented appendages termed prolegs, used in clinging, may be present (Fig. 4). Many female insects have a structure on the distal end of the abdomen, known as an ovipositor, used for guiding and depositing eggs. Ovipositors are of various lengths, sizes, and shapes depending on the species of insect and on its manner of ovipositing. Insects that lay their eggs on and not in materials have no ovipositor, as would be expected. Some insects, notably the female wasps, bees, and hornets, have a sting at the end of the abdomen, mainly for defense but in some cases for paralyzing prey.

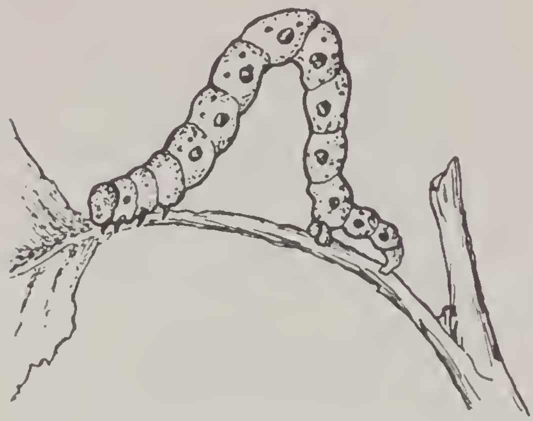

FIG. 4. A caterpillar, showing two pairs of prolegs on the abdomen in addition to the normal three pairs of legs on the thorax (redrawn from Lutz, Field Book of Insects).

THE MOUTH PARTS OF INSECTS

The way insects eat and what they eat determines to a great extent the type of control measures that may be effective against them.

THE CHEWING TYPE OF MOUTH PARTS. Insects' mouth parts show remarkable adaptations to their manner of feeding. The basic or primitive kind is the chewing type which permits its possessor to bite off and chew on, or into, external parts of a plant or to tunnel its way into some part of the plant (Figs. 3, 5, and 6). Essentially it consists of a labrum or upper lip which helps cover up the mouth parts from above; two heavy, chitinized grinding organs, the mandibles, which work on a lateral plane and help the insect tear off and crush its food; two slimmer, sharper, chitinized organs, the maxillae, which work in unison with the mandibles and help in tearing off bits of food; and one flap-like underlip, the labium, which serves to close up the mouth from underneath. Each maxilla has a fleshy lobe attached, which helps close up the sides of the mouth and which bears a short, segmented, antenna-like structure, the maxillary palp, with a sensory tip. The labium also bears a pair of shorter palps, labial palps, with sensory tips. It is thought that these sensory tips bear the organs of taste or smell, because the in-

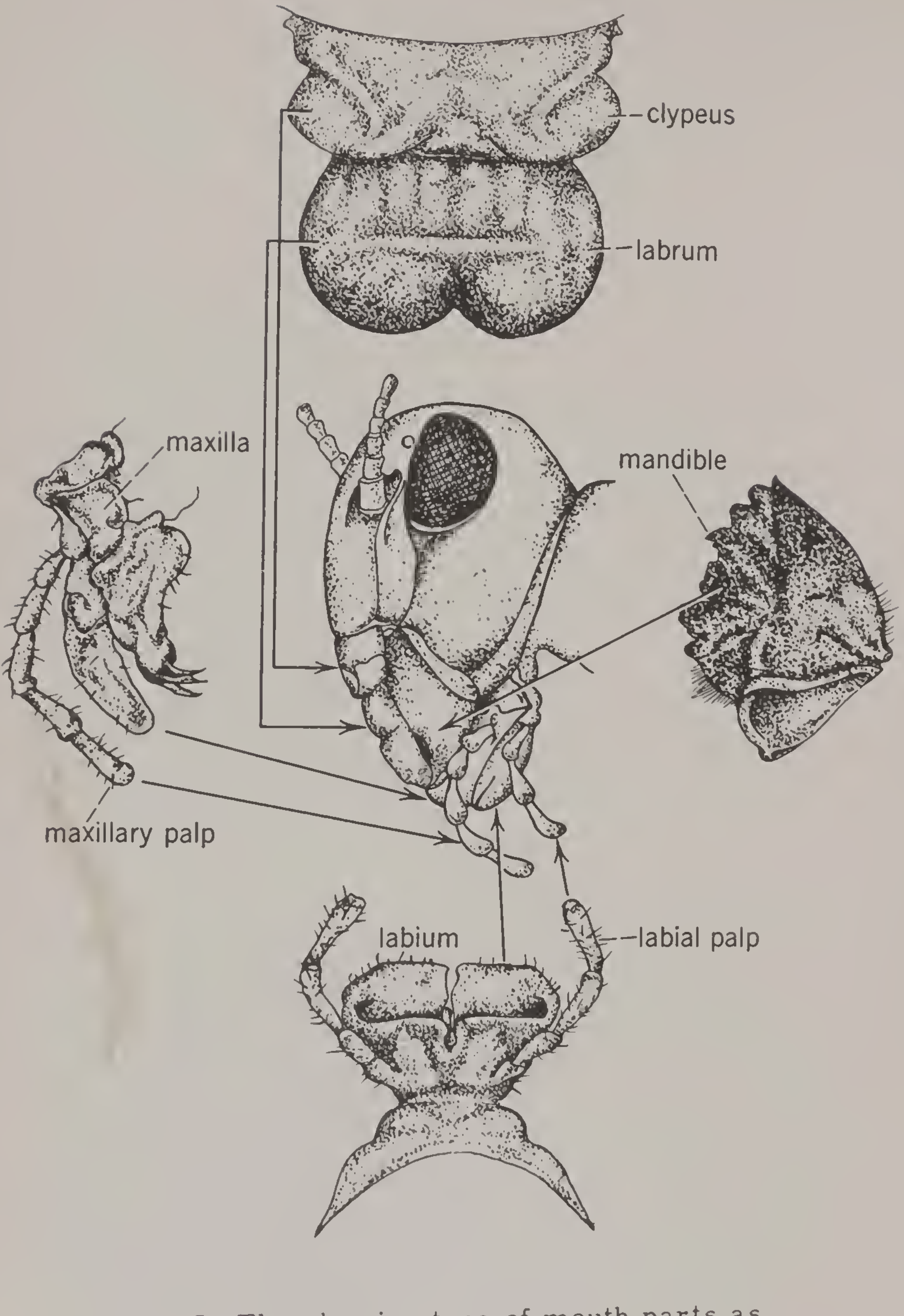

FIG. 5. The chewing type of mouth parts as typified by the grasshopper.

sects continuously muzzle their food with them while feeding. On the upper surface of the labium is a tongue-like projection called the hypopharynx which is also thought to have

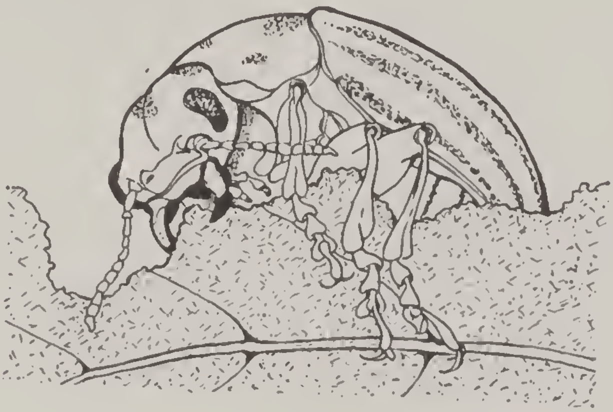

FIG. 6. A beetle chewing on a leaf (redrawn from Britton, Conn. Agr. Expt. Sta. Bull. 344).

sensory functions. All insects with elytra and those that in immature stages are "worm-like" have chewing-type mouth parts and are usually controlled by putting a poison that can take effect when swallowed on their natural food. Many of our most serious pests have this type of mouth parts, with which they defoliate plants, bore into them, or cause their fruit to be wormy.

THE PIERCING-SUCKING TYPE OF MOUTH PARTS. The typical piercing-sucking type of mouth parts (Fig. 7) is thought to have evolved from the chewing type in the following manner: the labium gradually elongated and rolled up lengthwise to form a hollow tube, with a longitudinal slit opening running down its full front length like a gutter on a roof; the labrum also elongated but became a slim, V-shaped structure partly covering up the longitudinal slit on the labium. The two mandibles and the two maxillae elongated but became extremely hair-like and pointed at the tip, for piercing. These are given the name of stylets and are found inside the beak formed by the labium and the labrum. Both the maxillary and labial palps were lost in many species. The stylets fit closely together with the two maxillae on the inside and the two mandibles, slightly shorter, on the outside. The two maxillae are grooved on the inside in such a way that when they fit closely together they form longitudinal capillary channels running into the head (Fig. 7C). One of these is for emitting saliva to mix with the plant juices before sucking them up, in much the same way that we mix our food with saliva for pre-digestion before swallowing it. The other is for sucking up the juice and saliva mixture into the stomach.

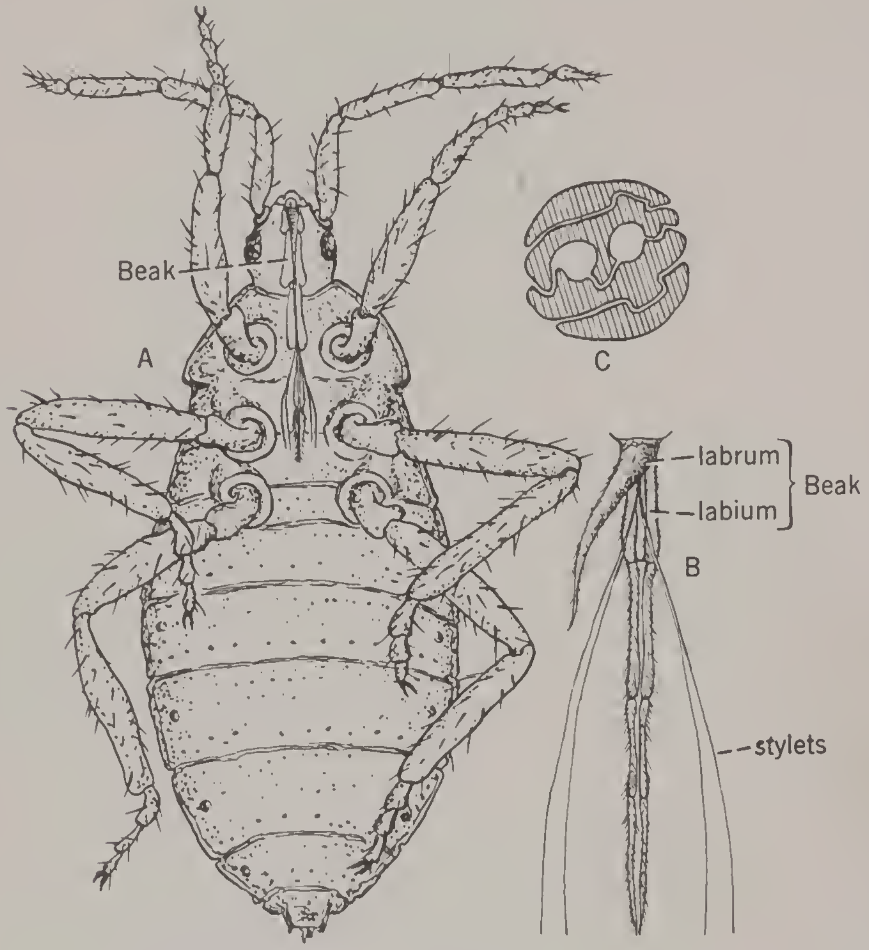

FIG. 7. A, ventral view of the squash bug showing beak folded back against body; B, beak enlarged, showing mouth parts; C, cross section tion of stylets, showing how the two maxillae mesh together to form two capillary tubes (diagrammatic).

In plant-sucking insects the stylets alone pierce the wound; the beak acts only as a protective sheath and elbows up out of the way as the stylets sink in deeper (Fig. 8), leaving no visible hole when withdrawn. In some insect forms the mouth parts or the saliva may carry the organisms of plant diseases or animal diseases, and these may be injected directly into the sap or the blood stream. Similar modifications of the chewing mouth parts produced such piercing-sucking mouth parts as are found in the blood-sucking flies, fleas, lice, and mosquitoes.

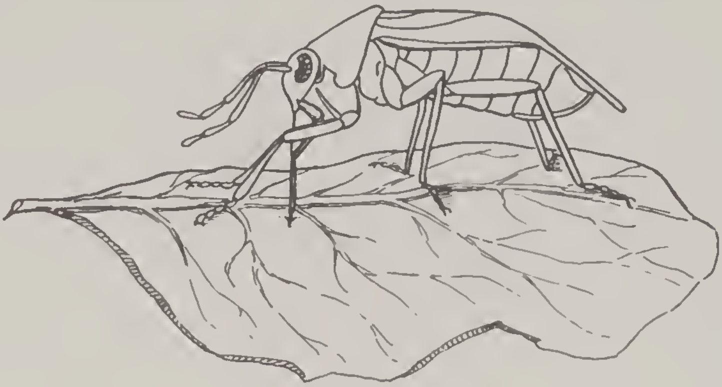

FIG. 8. A bug feeding on a leaf.

The piercing-sucking mouth parts are found in insects such as aphids, leafhoppers, scale insects, bugs, and cicadas. The injury to the plant from piercing-sucking insects results in discoloring and curling of foliage and weakening and drying up of twigs, limbs, and whole plants if the pests are abundant enough. Since these pests feed only from within it can be readily seen that a poison deposited on the surface of their food and effective only when taken into the stomach would be of no value against them. Poisons that contact the insects' bodies are effective for these pests.

THE RASPING-SUCKING TYPE OF MOUTH PARTS. A group of tiny insects known as thrips have modified mouth parts that are referred to as rasping-sucking (Fig. 9). They have a short, conical beak with three stylets that move in and out, rasping the tissue so that juice exudes. This juice is then sucked up through the conical beak. Tissue attacked by these pests tends to take on a whitish, mottled appearance and may later look rusty. Because of this manner of feeding, thrips may be controlled by a poison placed on the plant surface and swallowed with the juices, and also by body-contact poisons.

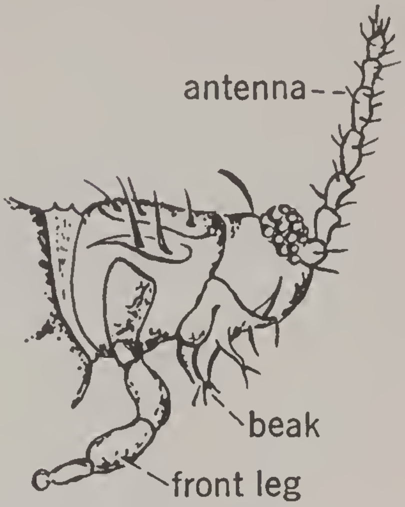

FIG. 9. Head of a thrips showing conical beak (redrawn from Metcalf and Flint, Fundamentals of Insect Life).

SPONGING TYPE OF MOUTH PARTS. Another type of modified sucking mouth parts is found in certain flies including the housefly (Fig. 10). Their mouth parts consist of a

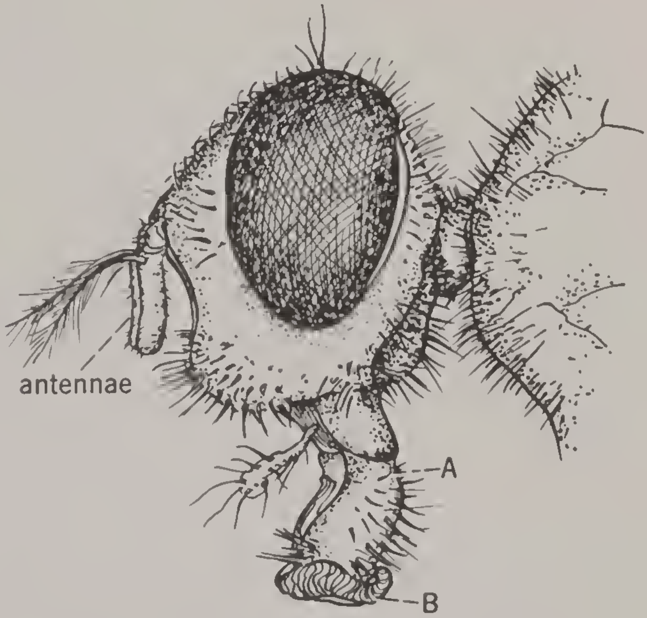

FIG. 10. Head of a housefly showing A, the fleshy proboscis with B, the sponge-like labella.

hinged, fleshy proboscis which is partly concealed in a cavity under the head, with a sponge-like organ at the end for sopping up liquids. To distinguish it from other types of sucking mouth parts it is referred to as a sponging type. It is of interest to know how these flies can feed on solid matter, as they often do, with such mouth parts. This is readily explained by the fact that flies first let out saliva to dissove or predigest the food, and then they suck it up. This type of insect may be killed by poison taken internally or by poisons that come in contact with the body.

SUCKING TYPE OF MOUTH PARTS. A simple sucking or siphoning type of mouth parts that is nothing more than a long tube is found in moths and butterflies (Fig. 11). This heart can actually be seen in action in many larvae with transparent chitin.

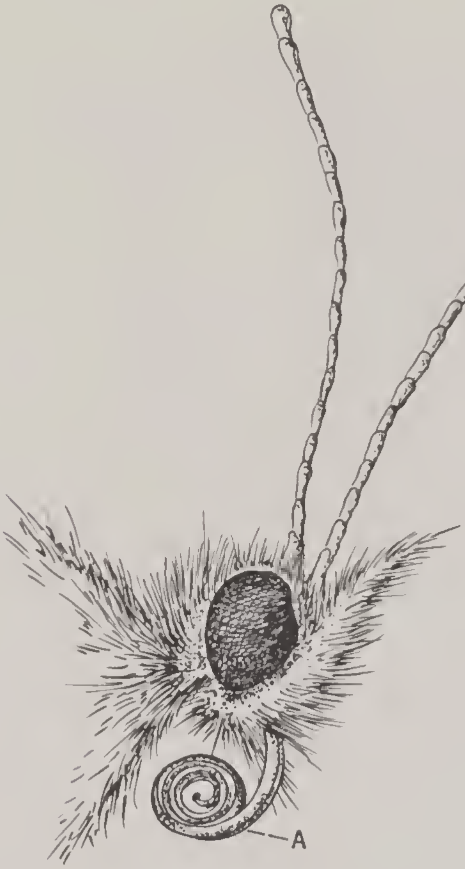

FIG. 11. Head of a butterfly showing A, the long, coiled-up sucking tube (proboscis). (Redrawn from Metcalf and Flint, (Destructive and Useful Insects.)

tube, also called tongue, is coiled like a watchspring in a groove on the ventral side of the head and is extended when the insects are feeding. Sometimes these tongues are much longer than the body of the insect; for example, hawk moths have a long proboscis adapted for taking nectar from flowers with deep corollas. Moths and butterflies are not harmful in themselves, since they can feed only on liquids, but in many of their immature stages they are serious pests. Because of their manner of feeding and their food, control by stomach poisons of insects having these mouth parts is not practical. Control is directed mainly at the insects that have chewing mouth parts in their immature stages.

CHEWING-LAPPING TYPE OF MOUTH PARTS. Finally, there is a group of insects with mouth parts of a combination type known as chewing-lapping (Fig. 12). These mouth

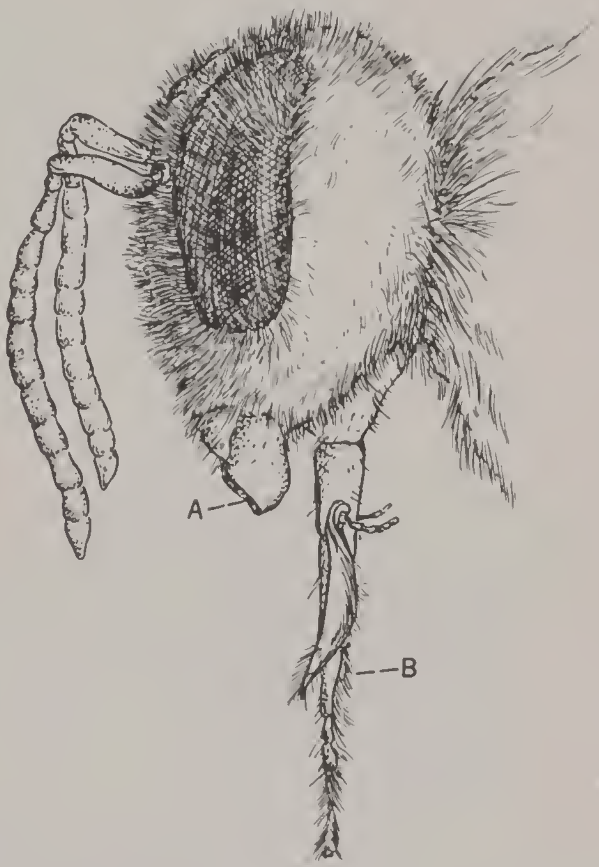

FIG. 12. Head of a bee. A, mandibles; B, lapping tongue.

parts are found in many types of bees. The mandibles have retained their original function as chewing organs, but the maxillae and labium have been modified into a slim, lapping organ for taking up liquids, especially the nectar of flowers. Since these insects are mainly beneficial, control methods are not practiced on them, but, on the contrary, controls used for others must be considered in the light of safety to many of these insects.

THE INTERNAL ORGANS OF INSECTS

Since all insecticides must take effect internally to destroy insects, it is important to know something of their internal make-up and of what may take place when certain insecticides are used.

Insects, though delicate-looking, are remarkably hard to kill. In fact, in many instances they are much more durable than higher animals subjected to the same type of mistreatment. A knowledge of the internal organs and of their function partly helps to explain why this is so (Fig. 13).

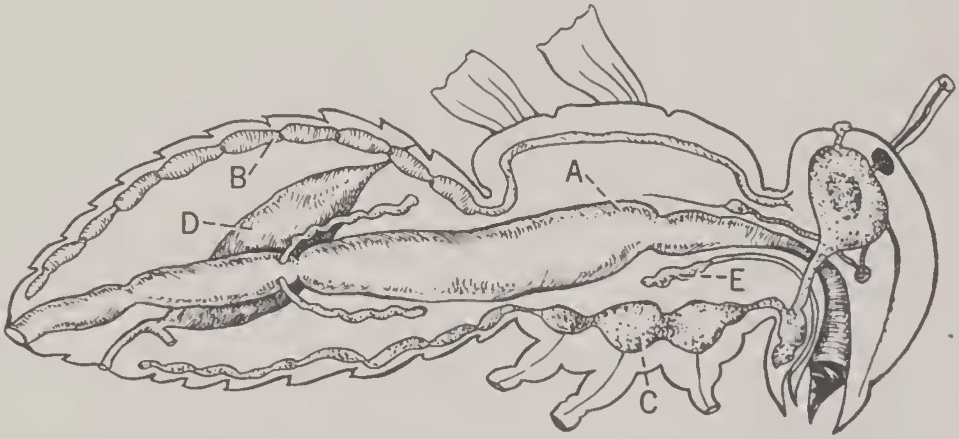

FIG. 13. The internal organs of an insect (diagrammatic). A, the alimentary canal; B, the circulatory organ; C, the central nervous system; D, the ovaries; E, the salivary glands (redrawn from Fernald, Applied Entomology).

INTESTINAL TRACT. The intestinal tract or alimentary canal in its simplest form is little more than a tube running the full length of the body (Fig. 13). Parts of this tube have become specialized for definite functions. In insects that feed on solid foods, the food particles are taken into the mouth where they are mixed with saliva and then passed on to the crop for storage. From the crop the food passes into the proventriculus or gizzard, a muscular, chitinous organ for grinding up the food. From there the food passes into the large intestine, where some digestion takes place, and continues into the small intestine, which is generally made up of many coils, where the rest of the digestion takes place. The undigested material then passes into a temporary storage chamber, the rectum, and out of the insect's body through the anus. This type of intestinal tract is very similar to that of a bird, and, like the birds, insects excrete their urates in solid form with the excreta. A stomach poison when it is swallowed by an insect probably takes effect in the large and small intestines. Some types of poisons may cause inflammation of the intestinal tract and slow death in a few days; others may be absorbed into the blood stream and may attack the nervous system, causing paralysis and quick death within a few hours.

Insects that feed on liquids only have no proventriculus and have a much shorter small intestine. Many insects such as bedbugs and carpet beetle larvae have the ability to withstand long periods of starvation and prolong their normal development up to a year or more.

THE CIRCULATORY SYSTEM OF INSECTS. Insects have what is known as an open circulatory system as opposed to our closed one, where veins, arteries and capillaries conduct the blood. Insects have no veins or arteries; the blood merely circulates among the internal tissues from points of greater pressure to points of lower pressure. The heart is a simple pumping organ located along the mid-dorsal side of the insect; it consists of a series of chambers with valves and a tube extending into the head (Fig. 13). The valves suck in the blood from the abdominal cavity and by a series of contracting movements push it forward into the head whence it gradually flows back into the abdomen because of the pressure differential. Accessory pulsating organs in the base of the legs of some insects help blood circulate into them. The

The blood of insects differs radically from ours in function. It does not serve like ours in respiration for carrying oxygen to cells and tissues and carrying carbon dioxide away, but it does carry foods from the intestines to the various tissues and cells. Since haemoglobin is generally absent in insect blood, it does not usually have the typical red color of our blood but is generally greenish or yellowish depending on the food dissolved in it. Insect blood has the power to clot, and therefore wounds are not necessarily fatal. The body temperature of insects is slightly above that of its environment and tends to parallel it—thus we speak of insects as being cold-blooded.

THE NERVOUS SYSTEM. Insects have a very generalized type of nervous system that can stand much more abuse than ours (Fig. 13). It consists of masses of nervous tissue called ganglia, joined together by nerve cords. Each ganglion, through branching nerve fibers, governs the movements of the appendages and the sensations of the segment or segments in which it is found. The large ganglion in the head, which corresponds to our brain, is only a coordinating organ for all the other ganglia, so that movements are purposeful and not erratic. Injury to any one ganglion in the body will prevent movements and sensations only in that part which it serves and is not necessarily fatal. Insecticides that cause paralysis of insects evidently affect the whole nervous system and not just individual ganglia. Some insecticides cause a rapid paralysis of insects within a few minutes, whereas others may take as much as a week to become effective, with loss of coordination as the first symptom.

THE RESPIRATORY SYSTEM. Insects have no lungs or nostrils; instead they breathe through a series of paired holes (spiracles) along the sides of the body. Since insect blood does not conduct oxygen, a direct type of respiration is necessary (Fig. 14). This is accomplished by interconnecting tubes called tracheae that orginate from the different spiracles and divide and subdivide into smaller and smaller tubes, the smallest of which are called tracheoles. These tracheoles ultimately reach every organ, tissue, and cell of the body, bringing them oxygen and carrying away carbon dioxide. The circulation of oxygen into, and carbon dioxide out of, the tracheae is mainly a matter of diffusion, with the exchange rate governed by the concentration gradient of the individual gases.

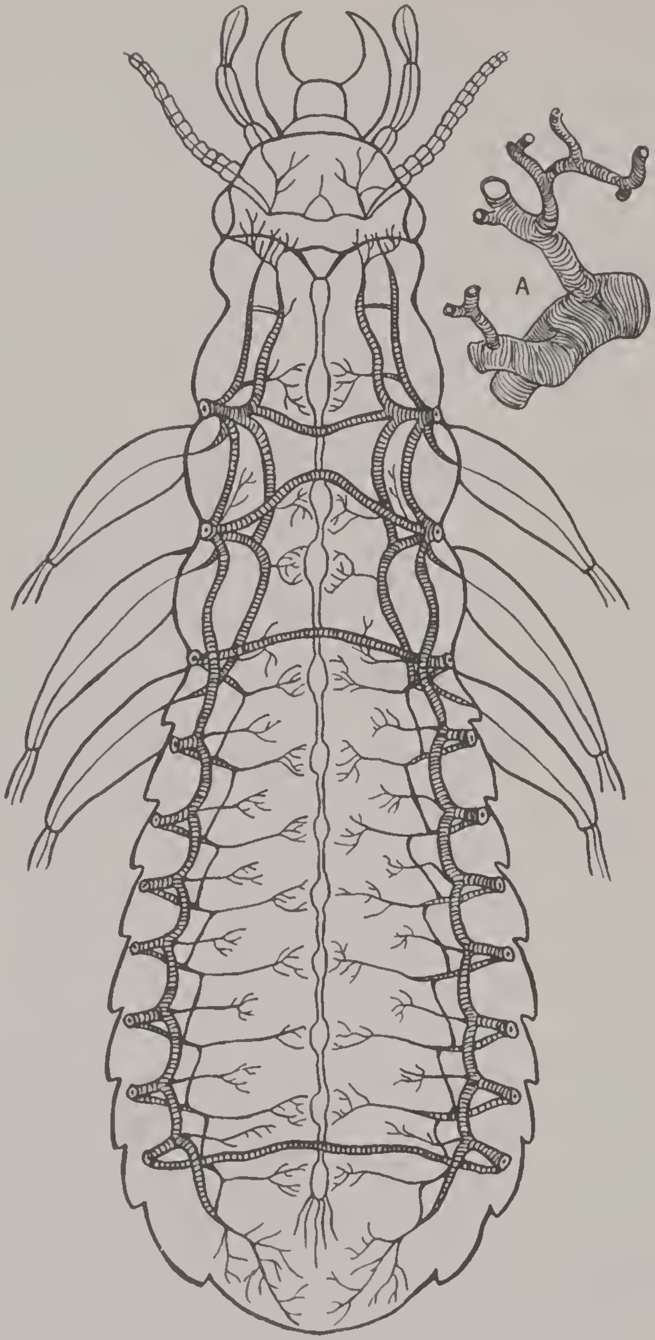

FIG. 14. The arrangement of the main tracheal tubes in an insect (diagrammatic) with A, an enlarged portion of the tracheae (redrawn from Fernald, Applied Entomology).

All spiracles are considered to have the same functions, and since they are interconnected by tracheae all but one or two may be clogged up and the insect will still be able to survive. Some insects may be kept under water for a day or more and may still recover when taken out, or they may be placed in a tightly closed bottle with food and live for days. Many contact poisons and all fumigants enter insects' bodies by way of the respiratory system. Since the respiratory system is directly connected to the nervous system, many of these materials cause quick paralysis. Insects may recover from this paralysis if they are not exposed to a high enough concentration or for a long enough time. Many apparently marvelous kills of insects 10 minutes after exposure have turned out a few hours later to be only partial kills, with many or most of the insects showing an amazing recuperative power.

REPRODUCTIVE ORGANS OF INSECTS. The reproductive organs of insects are located in the abdomen and in the female consist of a pair of ovaries with a common duct leading to an opening near the end of the abdomen or into an ovipositor extending from the abdomen. The male reproductive organs consist of two spermaries and a duct leading to a chitinized tubular structure.

ORGANS OF SECRETION. The organs of secretion in insects consist of the following types of glands adapted for various purposes:

The salivary glands are located in the thorax and open into the mouth parts. Because insect saliva sometimes carries disease-producing organisms, it is an important factor in their transmission to plants and animals. In many insect larvae the salivary glands are modified to spin webs used in dropping down when disturbed, in swinging from tree to tree in a breeze, or in building a protective case (cocoon) before they enter the pupal stage. In the case of silkworms, their ability to spin silken threads is utilized commercially.

The scent glands are located in various regions of the bodies of some insects. They may produce distasteful or foul-smelling substances used in defense, as in stinkbugs, or attractive scents for luring the opposite sex, as in some female moths.

Glands that produce waxy substances are found in many species, such as bees and scale insects. In scale insects, these glands may produce smooth, waxy coats covering the insect, or white, fluffy coats. These waxy, liquid-repelling coats make the control of these pests very difficult, as they help protect the insects or their eggs from insecticides.

The defense glands used in connection with stings are found at the posterior end of the abdomen in insects such as bees, wasps, hornets, and some ants. The stings are sharp, hollow structures attached to a poison sac from which the poison is ejected into the wound. Some caterpillars such as the saddleback caterpillar and the brown-tail moth caterpillar have poisonous, nettling hairs, the venom in which irritates anyone brushing against them.

QUESTIONS FOR DISCUSSION

1. What are the advantages of an exoskeleton over an endoskeleton?
2. In what ways do insects differ from one another?
3. In what ways do insects resemble one another?
4. How do insects differ from the higher animals?
5. Are there any advantages in having six legs?
6. What parts of an insect's leg correspond to our own?
7. Of what significance is the distribution of the spiracles?
8. What are the structural features that are responsible for the success of the insect type of organization?
9. Name some external insect structures that show remarkable adaptations to their environment.
10. How could a knowledge of external structures and their functions help in insect pest control?
11. In general, what would be the difference between the manner of ovipositing in insects with ovipositors and those without?
12. State some sexual differences in insects.
13. How is it possible for some sucking insects to feed on solid food?
14. Why is it not advisable to spray fruit orchards during the blossoming period?
15. What are the differences between plant injury produced by chewing insects and that by piercing-sucking insects? Which injures a plant more?

16. What type of mouth parts must a boring insect have? Why?

17. Some insects, like the clothes moth, do not feed in the adult stage. How do they survive and reproduce?

18. If an insect has a beak or snout, how could you tell whether it was piercing-sucking or chewing? Could you do so without looking at the mouth parts?

19. Can you give any reasons why curculios (snout beetles) are hard to control?

20. What use does a honey bee make of its double-functioning mouth parts?

21. In what parts of plants is most of the food found? Does this correspond with points of greatest insect attack?

22. Why can a scale insect remain stationary throughout its life and still obtain ample food?

23. Why can an insect be kept alive for weeks in a tightly closed bottle?

24. What will happen if an insect's head is placed under water? If its body is placed under water?

25. What are the advantages of a generalized nervous system as found in insects?

26. Criticize the following statement: Insects react in certain ways because they wish to protect themselves or accomplish something.

27. Do you know of any instances when insects seemed to use the power of reasoning?

28. Name some methods utilized by insects to protect themselves from their enemies.

29. What are some of the ways in which we utilize the senses of insects in killing them?

30. Name a problem in agriculture in which a knowledge of insect morphology would be valuable.

Chapter 2

THE DEVELOPMENT OF INSECTS

There are more misconceptions about the stages of insect life and their relationships to one another than about those of any higher animal. This is because not all insects follow the same pattern of development as mammals. Each species has its own peculiar pattern of growth and development known as its metamorphosis.

REPRODUCTION AND THE EGG STAGE OF INSECTS

FERTILIZATION IN INSECTS. The life of each insect may be said to begin with the formation of an egg in the ovary of a female insect. As in the higher animals, fertilization of the egg by the sperm from the male insect is necessary in most species for the production of an individual. However, many female insects are capable of producing living, normal young without the necessity of mating. This evolutionary development, reproduction without fertilization, is referred to as parthenogenesis. As may be expected, some of our most important insect pests are parthenogenetic, with only females being produced. Males have never been found in many species such as the alfalfa snout beetle, the strawberry weevil, the white-fringed beetle, and some scale insects and thrips. In other species, notably aphids and some thrips, partial parthenogenesis occurs, some generations consisting only of females, with males appearing and fertilization taking place in occasional generations. In honey bees the queen evidently has the ability to prevent fertilization of some eggs, which develop into males or "drones," whereas the fertilized eggs produce workers (undeveloped females) or queens.

THE EGGS OF INSECTS. The eggs of different species of insects are not as varied in size, shape, and appearance as the insects that lay them (Fig. 15). They are generally overlooked because they are very small, placed in concealment, and tend to blend with their surroundings. It is often very important to be able to tell the exact kind of insect that will develop from an egg, because many pests may be controlled in that stage, or controls may be prepared to take care of the susceptible stages of growth when they appear. The eggs of many species of insects may be recognized by a careful examination and by a consideration of distinguishing characteristics.

The eggs of different species of insects differ in size, shape, color, location, attachment, kind of scar made in the laying and sculpturing of the eggshell. In addition, some are laid singly and some in definite or indefinite masses; some are free and some are cemented together; some are uncovered and some are covered with hairs, cement, or paper-like, wax-like secretions.

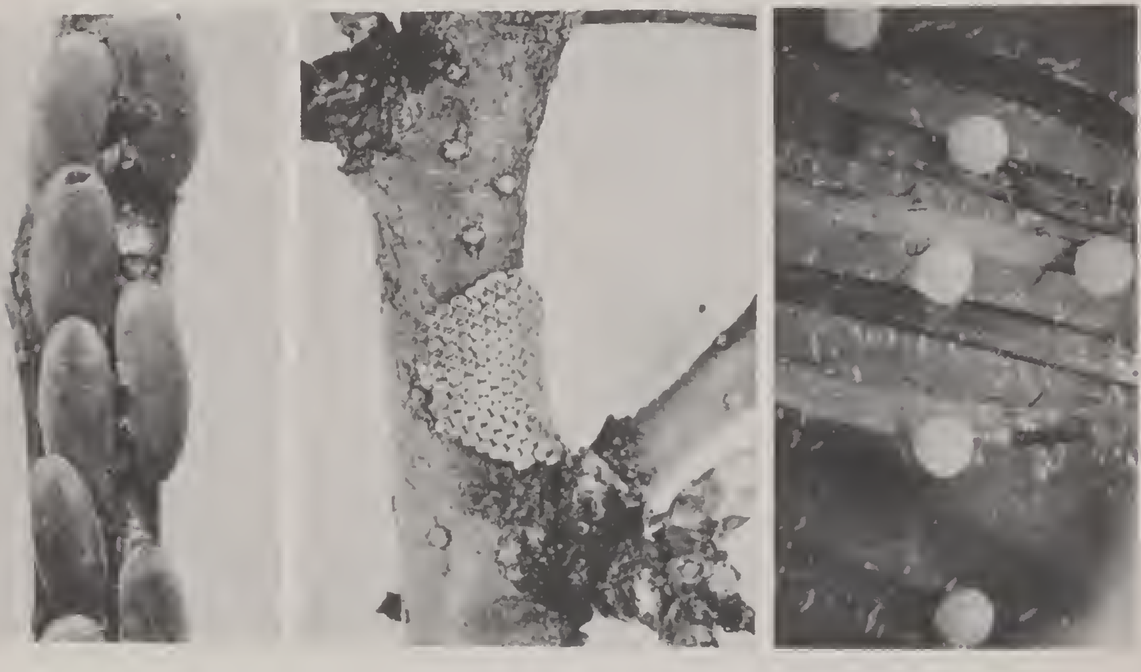

FIG. 15. The eggs of insects. A, katydid eggs on a twig; B, fall cankerworm eggs; C, corn earworm eggs attached to corn silks (all greatly enlarged).

Some insects' eggs are so small that their characteristics can be seen only under a microscope, but all are generally laid in such a situation that the young when hatched may find suitable food. Sometimes, as in moths and butterflies, the adults deposit their eggs on food plants suitable for the larvae, although the adults themselves do not feed on these plants. There is no maternal instinct in insects except in a few exceptional cases where insects have been observed to guard their eggs, or with the social insects, such as bees and ants, which actually feed and take care of the young in the helpless, immature states of growth.

Eggs of insects may be laid all at one time, as by the tussock moths; or a few a day for many days, as by the imported cabbage-worm; or a number of successive batches of eggs may be produced at intervals, such as in the case of the squash bug and the Mexican bean beetle. The female insect generally dies shortly after she has completed egg laying.

REPRODUCTIVE POWERS OF INSECTS. Insects differ greatly in the number of eggs or young that a single female may produce. The number varies from a few dozen in some species to a million or more by the queens of social insects. The average number for most plant pests probably lies between 100 to 500, with many species laying as many as 1000 to 2000 eggs. This great reproductive potential far exceeds that of the higher animals, and many unbelievable examples of insects' reproductive powers have been cited under ideal conditions of food and survival.

One classic example is that of a pair of flies that could produce enough progeny during one active season if they all lived to cover the earth to a depth of 47 feet, allowing 1/8 cubic inch to a fly. Still another example is that of a single aphid egg giving rise to 1,111,111,111 descendants in a single season, allowing 10 generations a season and only 10 young per aphid, all being parthenogenetic. The number of individuals that could theoretically be produced in a season, allowing 100 young per female and more than 10 generations a season, which is common in many species of aphids, "would be sufficient to cover the entire world completely with a continuous layer of aphids." Fortunately, natural checks prevent any such tremendous increases, but even with these natural checks, which allow only a small percentage of individuals to die naturally, there are enough pests to cause great damage to crops and under favorable conditions in some seasons to cause tremendous losses.

DURATION OF THE EGG STAGE. Under normal conditions the time spent within the egg varies greatly with different insect species. It may last from only a few hours (as in certain flies) to 1 to 2 weeks or more (in most insects), depending mainly on temperatures. Unlike the eggs of birds, insect eggs do not require extra heat to begin development. Development begins when the temperature reaches a certain minimum (55-60° F.) and increases in speed up to a definite maximum temperature (95-100° F.), after which it tends to slow down. When temperatures drop below the minimum for development but above freezing for short periods the eggs are not killed, and development continues when the temperature again rises. Thus Mexican bean beetle eggs may take 1 week to hatch when temperatures are about 85° F. and 2 to 3 weeks or more when temperatures average around 65° F. Eggs of some insects such as tent caterpillars and aphids must undergo a freezing or a dry period before they will hatch. Many insects overwinter in the egg stage, all other stages dying off.

Many insects that lay their eggs exposed on trees and shrubs (aphids, scale insects, leaf roller, etc.) may be controlled in that stage by insecticides known as ovicides. For these pests insecticides are generally applied in the dormant season when potent materials may be used without danger of injury to the plants.

TYPES OF INSECT REPRODUCTION. Three types of reproduction are found in insects: oviparous, ovoviviparous, and viviparous. Oviparous reproduction is reproduction by bringing forth eggs that after various periods hatch and produce young. The great majority of our insects reproduce in this fashion. In ovoviviparous reproduction the eggs are retained within the body of the insect until they have hatched, and the insect gives birth to active young. Most aphids, except for one generation in the fall, and some scale insects, such as the San Jose scale, the soft brown scale, and the citrus mealy bug, are ovoviviparous. Viviparous reproduction as found in man and in other mammals is not common in insects. In this type of reproduction the embryos develop in the body cavity and feed on certain secretions produced therein. When the embryos are fully mature they are brought forth alive and active. The tsetse fly that causes African sleeping sickness and the sheep tick, a wingless fly that sucks the blood of sheep, are examples of this type of reproduction.

METAMORPHOSIS OF INSECTS

Metamorphosis refers to any change in form, structure, and appearance of an animal between birth and maturity. Insects may be divided into three groups with reference to a metamorphosis.

INSECTS WITHOUT A METAMORPHOSIS. These insects upon emerging from the eggs are essentially like the adult except for size. To become adult, they undergo a series of molts at intervals, each time increasing in size until the sexually mature stage is reached. Only two relatively unimportant groups of insects have this type of metamorphosis: the Thysanura, which includes the household pests known as silver fish and fire brats; and the Collembola, which includes the springtails, one species of which attacks garden plants. These insects are wingless and are considered to be primitive types in the evolutionary scale of insects. They have chewing types of mouth parts.

INSECTS WITH A GRADUAL OR INCOMPLETE METAMORPHOSIS. All winged insects must undergo a metamorphosis during their development, since no insect has visible

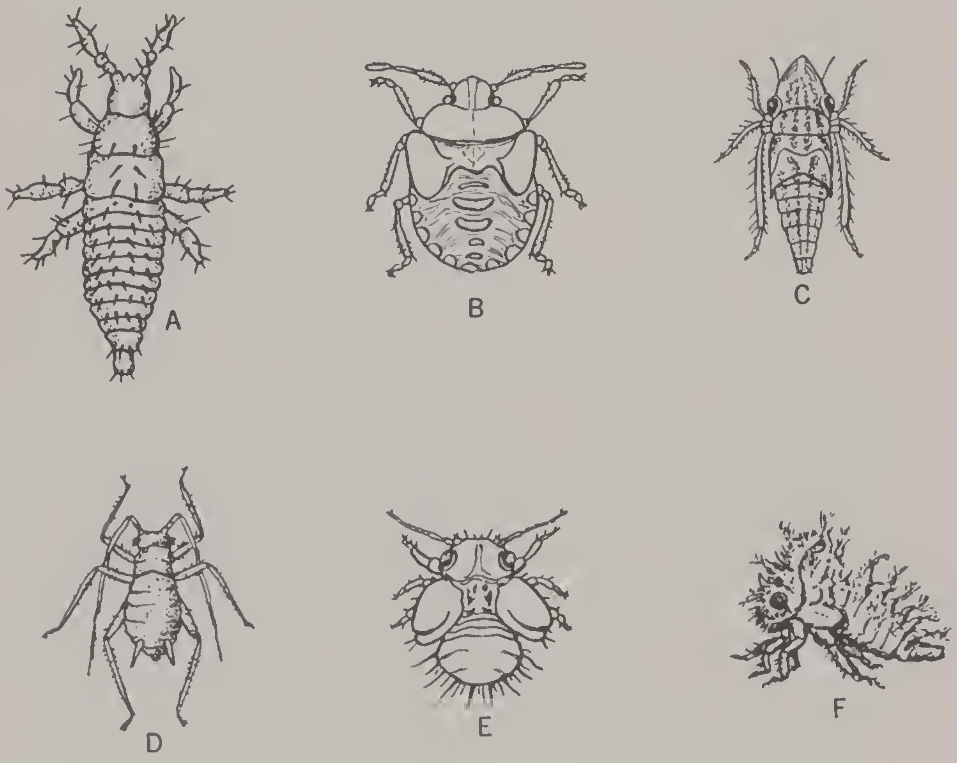

FIG. 16. Nymphs. A, thrips; B, plant bug; C, leafhopper; D, aphid; E, psyllid; F, treehopper (redrawn from various sources).

wings when it emerges from the eggshell. When insects with a gradual or incomplete metamorphosis hatch they resemble adult insects but completely lack wings (Fig. 16). Except for some aquatic forms, they have the same types of appendages and structures and generally have the same habits and food plants as the parents. The young of the terrestrial segment of this group are called nymphs and the aquatic forms are usually called naiads. Nymphs grow through a series of molts. Each time they molt they become larger. The periods between molts are called instars. The wing buds are scarcely noticeable on the very young nymphs, but after each molt they become larger until they expand into the fully developed wings of the adult after the final molt (Fig. 17). The number of molts and instars in insects undergoing a gradual or incomplete metamorphosis remains constant for the species but tends to vary greatly in different species. The time spent in each instar depends mainly on temperature and on nutritional conditions. Under normal summer conditions most insects with this metamorphosis take about a month to develop from egg to adult.

Most insects that have a gradual metamorphosis have piercing-sucking mouth parts, with the exception of the naiads and of the group known as the Orthoptera which includes the grasshoppers, crickets, and katydids. Insects having this type of metamorphosis include some of our worst pests, such as aphids, scale insects, leafhoppers, thrips, grasshoppers, and plant bugs. These insects are generally most easily controlled in the young nymphal stages; the adults tend to be much more resistant or may fly away from spray or dust applications.

INSECTS WITH A COMPLETE OR COMPLEX METAMORPHOSIS. The young of insects with a complete metamorphosis show no resemblance to the adult insects into which they will develop. They tend to be "worm-like" and are known as larvae in contrast to nymphs (Figs. 18 and 19). Larvae show no traces of wings externally during any period of growth and may differ greatly in habits from the adult. Larvae also undergo molts and pass through several instars before they reach the size characteristic of their species. In structure they differ greatly from adults, although they have the general characteristics of insects. They tend to have elongated bodies that may bear accessory legs known as prolegs to help them in locomotion. They have only simple eyes, and the larvae of flies, bees, moths, and butterflies have mouth parts and feeding habits differing greatly from those of the adult. It is

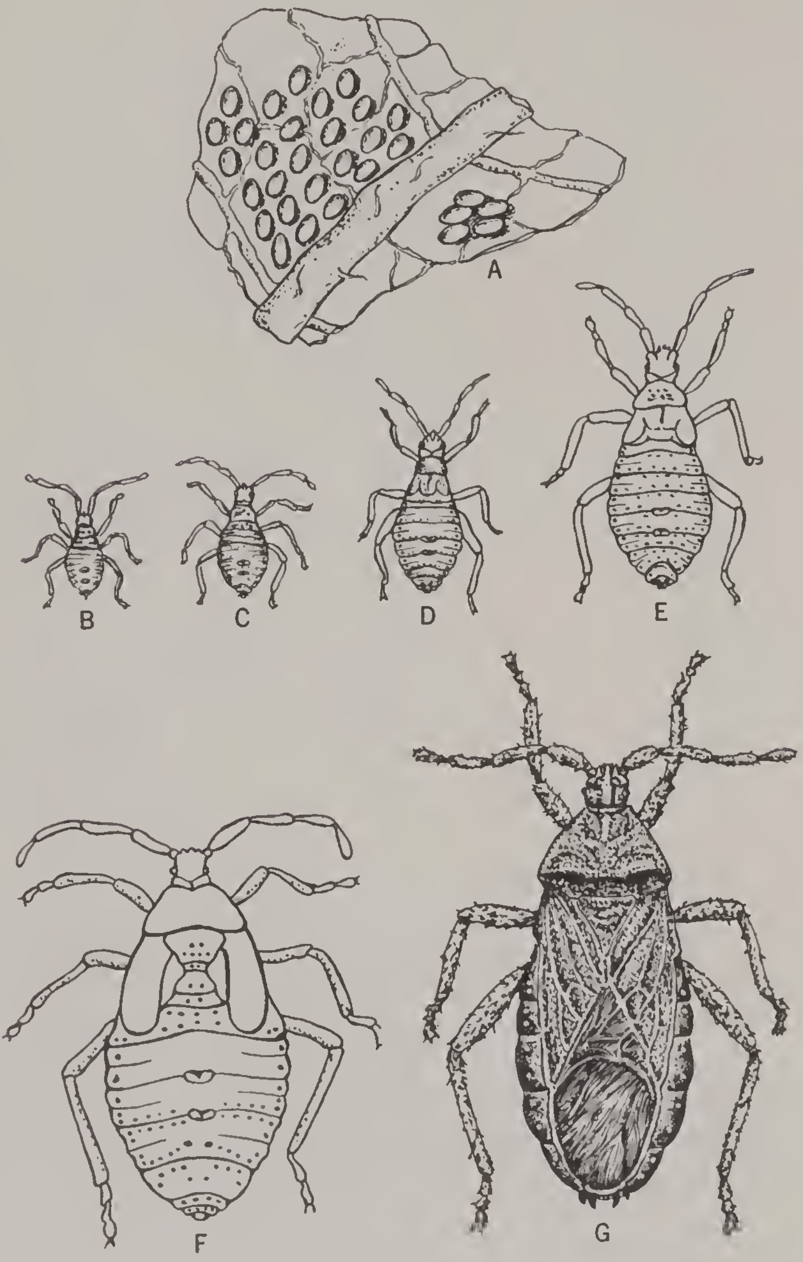

FIG. 17. Gradual metamorphosis as illustrated by the squash bug (*Anasa tristis*). A, eggs on the underside of a leaf; B, C, D, E, and F, five nymphal stages, the latter ones showing wing buds; G, the adult.

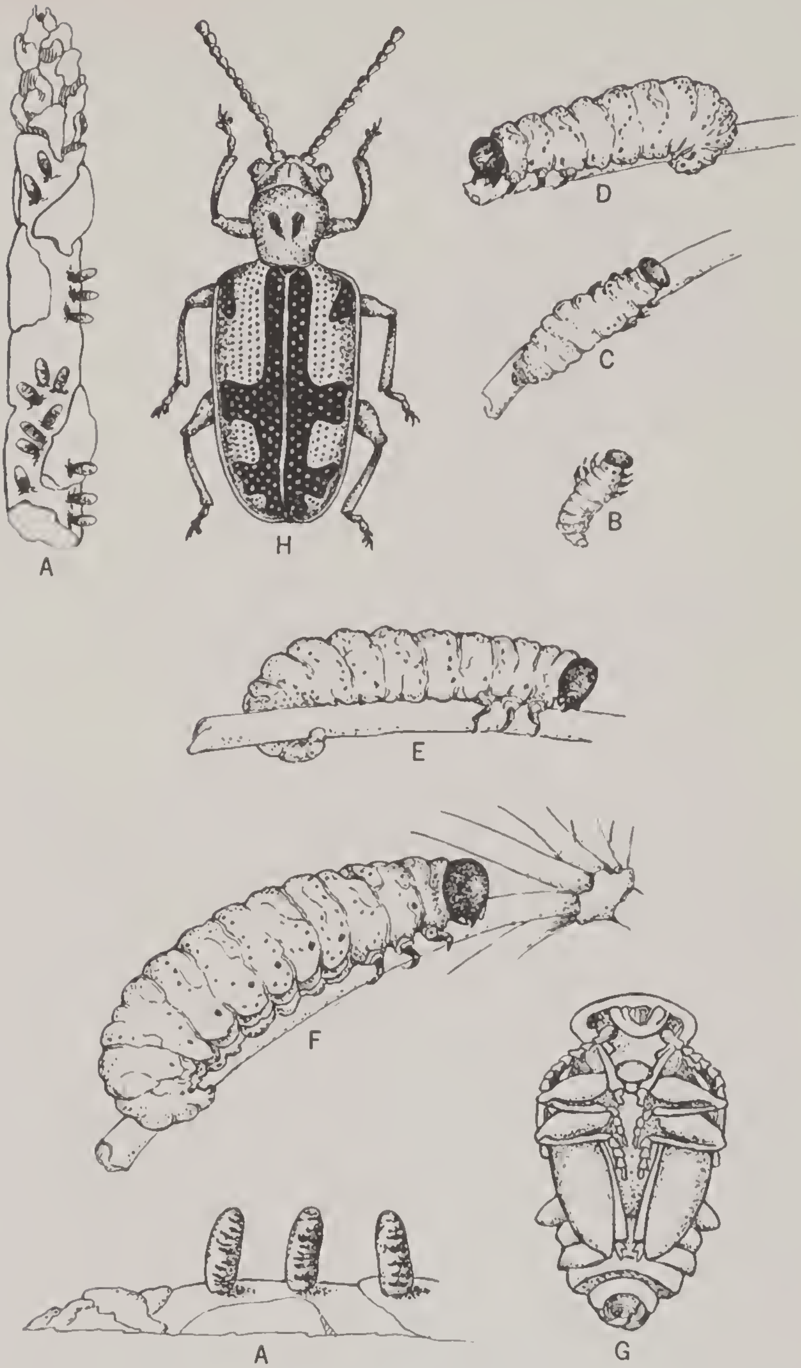

FIG. 18. Complete metamorphosis as illustrated by the common asparagus beetle (*Crioceris asparagi*). A, eggs on shoot; B, C, D, E, and F, five larval stages; G, pupa; H, adult (redrawn from *U.S. Dept. Agr. Farmers' Bull.* 1371, with modifications).

during the larval stages that these insects generally do the most damage, because that is when feeding and growth takes place.

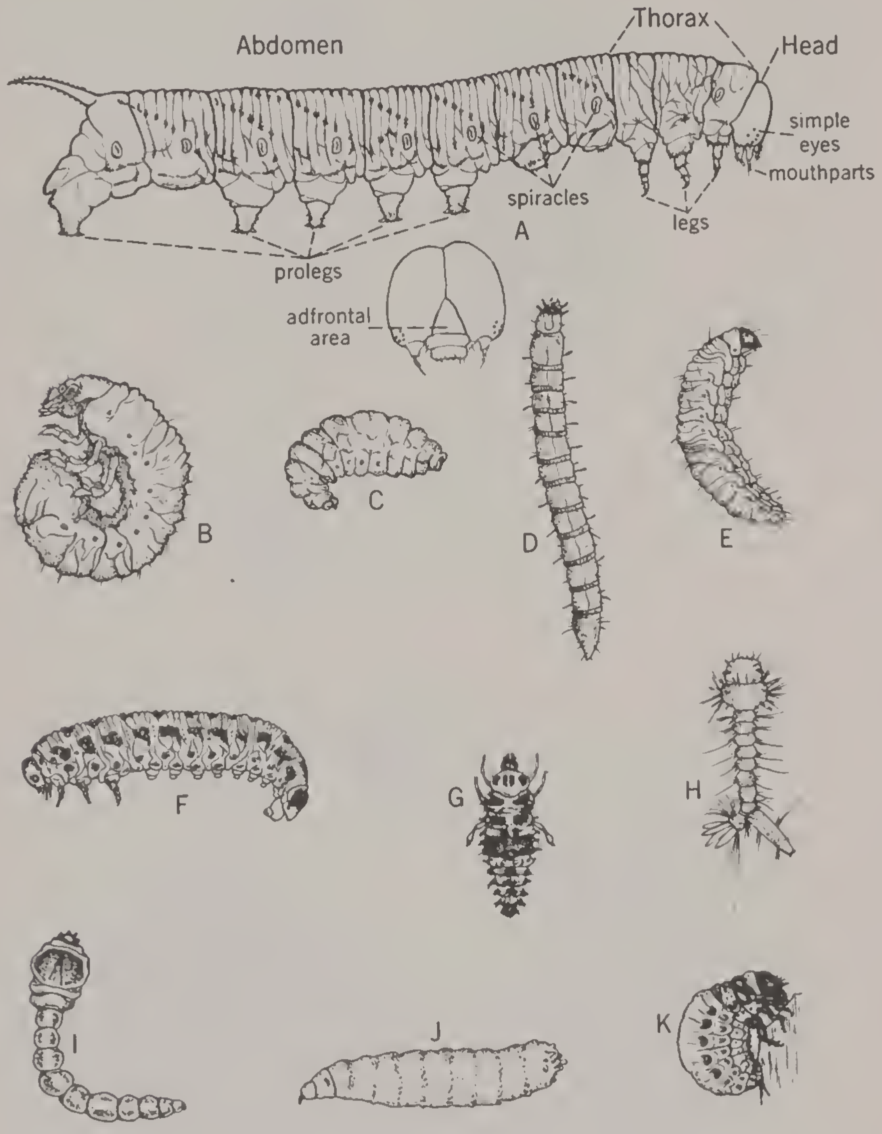

FIG. 19. The larvae of insects. A, moth (caterpillar); B, beetle (grub); C, bee; D, beetle (wireworm); E, beetle (curculio); F, sawfly; G, lady beetle; H, mosquito; I, beetle (wood borer); J, fly (maggot); K, beetle (redrawn from various sources).

INSECT PUPAE. When a larva reaches its full growth, a striking change takes place. The larva sheds its skin, and all the body parts of the adult insect including wing buds appear folded up against the body. This is known as the pupal stage, and the insect is referred to as a pupa (Fig. 20). The pupa is quiescent and capable at the most only of wriggling its abdomen. It is during this stage that all the internal organs of the insect change into the adult organs. When the change-over is complete the insect wriggles out of its pupal skin, expands its wings, and after a short period of drying is ready to fly and begin its adult life. The pupal stage of growth, because of its helplessness, is generally concealed in the soil or in some other protected place or bundled up in a silken case known as a cocoon. The fly larva uses its dry, hardened skin to form a pupal case known as a puparium (Fig. 20). The pupal stage is generally the most resistant to insecticides and also the least exposed, therefore control should be directed at the insects in more susceptible stages of growth.

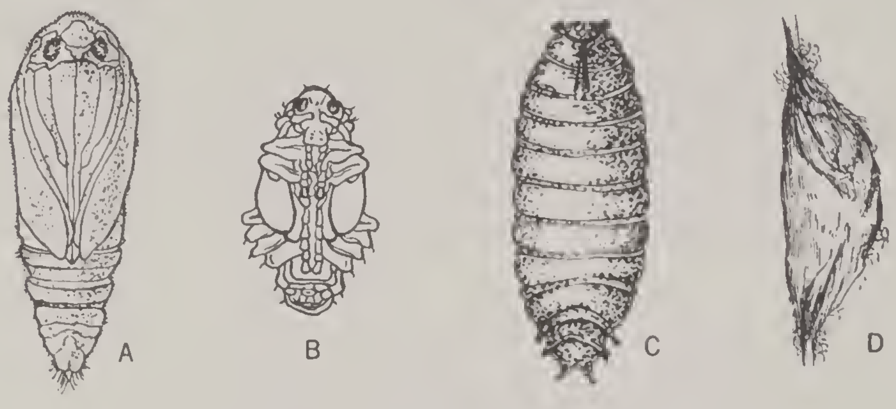

FIG. 20. The pupal stage of insects. A, moth; B, beetle; C, puparium of a fly; D, cocoon of a moth.

INSECT GROWTH. Among insects, all increase in size takes place in the nymphal or larval stages that follow immediately after hatching. No fully mature insect whether winged or wingless increases in size. Once insects have acquired wings or are capable of reproduction they are considered adults. No immature insect has functional wings. This should make it clear that small beetles will not grow into large beetles, and that small flies will not grow into large flies. They are simply of a different species that characteristically attains that size, or sometimes they may be runts of the same species, caused by inadequate nutrition or unfavorable environmental conditions during growth.

Some types of larvae, because of their distinct characteristics, have been given definite names (Fig. 19). Caterpillars are the larvae of moths and butterflies; grubs are the larvae of beetles; maggots are the larvae of flies; cutworms are the larvae of a certain group of moths; and wireworms are the larvae of click beetles. Larvae have characteristics that make it possible to tell what type of insect they will develop into; and often the exact species can be recognized in its larval stage.

IDENTIFICATION OF IMMATURE INSECTS

A. Wing pads usually present, never functional, compound eyes present, sometimes brightly colored. Shape and appendages similar to adults. Legs usually large, two claws on tarsus. Mouth parts like parents'—chewing or piercing-sucking. Nymphs and naiads.

B. No signs of wings or wing pads, no compound eyes, body soft, thin-skinned, sometimes hairy, abdomen three or four times length of head and thorax together, shape "worm-like." Chewing type mouth parts, habits often very different from adults. Larvae.

C. Legs and wing pads encased in extra membrane and folded against body, with some exceptions never used for locomotion. Inactive except for wriggling of abdomen by some forms when disturbed. Shape and appendages like adult. Often encased in cocoon, puparium, or soil. Pupae.

IDENTIFICATION OF AGRICULTURALLY IMPORTANT LARVAE

A. With thoracic legs but without abdominal prolegs.

1. Head distinct, sometimes depressed, mouth directed forward or downward, no adfrontal area. Larvae of Coleoptera (beetles).
2. Head usually globular, adfrontal area usually present, mouth directed downward, spinneret present near end

of labium. Larvae of *Lepidoptera* (moths, butterflies).

B. With thoracic legs and abdominal prolegs.
   1. Two, three, or five pairs of prolegs with tiny hooks, more than one pair of simple eyes or none on each side of head. Larvae of *Lepidoptera*.
   2. Prolegs, usually six to eight pairs, no tiny hooks, one simple eye or none on each side of head. Larvae of *Hymenoptera* (sawflies).

C. No thoracic legs, no prolegs, distinct head.
   1. Labium with a projecting median spinneret. Larvae of *Lepidoptera*.
   2. Body generally short, frequently U-shaped, pair of spiracles on each of the principle abdominal segments. Larvae of *Coleoptera* (curculios).

D. No thoracic legs, indistinct head, or head apparently wanting.
   1. Abdomen with several pairs of spiracles or none, no antennae, body tapers somewhat at both ends. Soft, white or yellow grubs found in wax, in paper cells, in bodies of insects, or in galls. Larvae of *Hymenoptera* (bees, wasps, ants).
   2. Abdomen usually with one pair of spiracles located on blunt end. Head end pointed. Mouth parts usually consisting of a pair of hooks. Larvae of *Diptera* (flies).

PUPAE

A. With appendages usually fast to the body wall, often in cocoons. Abdominal segments often capable of much wriggling. *Lepidoptera*.

B. With appendages nearly always free, body wall generally thin, soft, and pale colored, rarely in cocoons. *Coleoptera*.

C. With appendages free, commonly encased in cocoons. *Hymenoptera*.

D. With appendages generally free, usually encased in a puparium. *Diptera*.

QUESTIONS FOR DISCUSSION

1. In what stages are insects usually harmless to crops? Why?

2. What insects are usually harmless to plants in the adult stage?

3. What characteristics of insect larvae usually determine whether they will develop into beetles, curculios, moths or butterflies, flies, or sawflies?

4. What larvae have no legs at all? How are they distinguished from one another?

5. Of what importance is it to know into what a larva will develop?

6. Give the main structural differences between a larva and an adult; a pupa and a larva; a nymph and an adult.

7. At what stages are insects usually most susceptible to insecticides?

8. In general, do nymphs and adults have the same habits? Do caterpillars and moths?

9. Why are insect eggs so inconspicuous?

10. Can an insect species be determined from eggs alone?

11. What is the value of recognizing insect eggs?

12. What may determine whether one generation of insects or several occurs during the summer months?

13. Why is an insect considered an adult once it has acquired functional wings?

14. Is there any truth in the statement that little flies grow into big flies? Why?

15. At what stages are insects usually the most harmful to plants? Why?

16. Are all adult insects winged? Name some that are not.

17. If an organism is flying, and it isn't a bird or a bat, what is it?

18. During what stages does an insect grow larger and fatter?

19. What determines the number of molts a nymph or a larva will undergo before transforming to the next stage?

20. How does an insect grow?

21. What insects remain in one place during most of their life? What adaptations enable them to do this?

22. Differentiate between true worms and insect larvae.

23. At which stages of growth are insects the most defenseless? How are they usually protected in these stages?

24. Which type of reproduction in insects is more efficient: sexual or parthenogenetic?

Chapter 3

THE SEASONAL LIFE HISTORY OF INSECTS

The seasonal life history of an insect is the record of all the stages through which the species passes, the approximate length of time spent in each stage, and the number of life cycles produced in a year. In addition it is also a record of all that the insect does during its life. No grower can afford to overlook this information about his important crop pests if he is to deal with them efficiently and effectively.

The life history may generally be divided into an active and a dormant period (Fig. 21). The active period may in addition be divided into the primary life cycle or generation, beginning with the egg stage when activity starts in the spring, and successive similar secondary life cycles. In many pests there may be an overlapping of life cycles with all stages being present at the same time. This is mainly because adults reproduce over a long period or come out of hibernation over an extended period.

INSECT HIBERNATION. The stage in which an insect overwinters varies among the different species of insects. Some insects completing the next-to-the-last as well as the last secondary cycle may produce the overwintering stage. For example, many codling moth larvae of the first brood in northern regions may not transfer into pupae but may remain dormant along with the second-brood larvae until the next spring. There are also cases where individuals of the overwintering stage may continue dormancy through the entire summer and finally complete their life cycle the following summer. The apple maggot which overwinters in a puparium in the soil has been observed to do this.

Insects generally hibernate in only one of their life stages, according to the species. They may hibernate in the egg stage on plants, in plant tissue, and in the soil; as full-grown larvae in protected places on plants, in plants, in the soil, and under objects; as adults in protected places in the woods, hedgerows, stone walls, and trash piles; or as partly grown nymphs in protected places. In tropical climates or in greenhouses there may be no dormant period, and generations may follow one another continuously; or where dry and rainy seasons occur many insects go in the dry season into a dormant stage similar to hibernation but referred to as estivation. The insects come out of estivation as soon as the rainy season begins.

Only those insects such as aphids in the egg stage and scale insects, that hibernate externally on trees and shrubs,

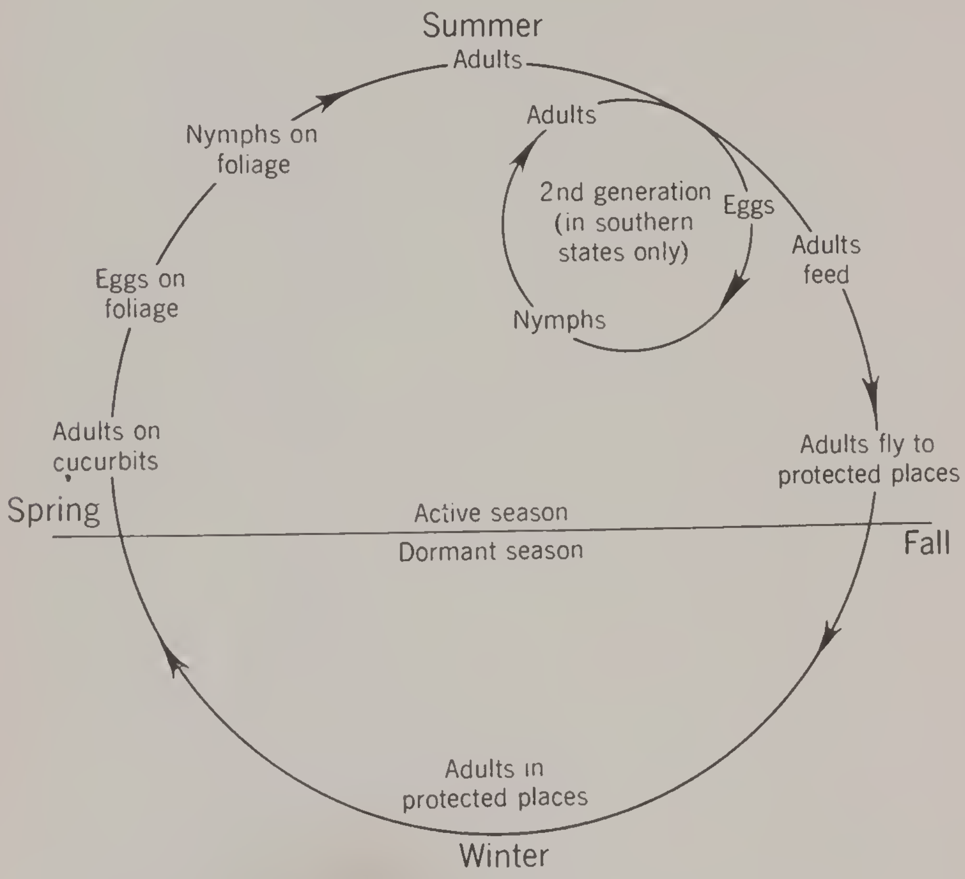

FIG. 21. The life history of the squash bug.

may be controlled by sprays applied during the dormant season of the plants.

INSECT ACTIVITIES. The dormant insects become active when warm weather arrives in the spring—those that are immature continue their development, and those that overwinter as adults leave their hibernating quarters and seek food in fields and gardens. There they begin a new generation that goes through either a gradual or a complete metamorphosis according to their nature. The number of generations depends mainly on the inherent traits of the insects as well as on the weather conditions during the active season. Some pests may complete only one life cycle in a year (squash vine borer); some only one life cycle in 2 years (leopard moth); some only one life cycle in 3 years (common white grub); but many will complete as many generations in an active season as weather and climate allow. The longest-lived insect is the periodical cicada which takes seventeen years to complete its life cycle. Insects generally die shortly after they have lost their reproductive powers.

HOW WEATHER AND CLIMATE AFFECT INSECTS

Unfavorable weather is undoubtedly one of the main factors in leveling or reducing insect populations. Climate determines what insect pests are present and how many generations are possible in a single active season, but day-to-day weather plays a primary part in influencing insect abundance and damage.

THE EFFECT OF TEMPERATURE ON INSECTS. The general effect of temperature on insects is illustrated by Fig. 22. The optimum effective temperature range includes temperatures in which insects will thrive and multiply at the maximum rate. Optimum conditions vary with each insect species and even with different stages of the same species. Some insects such as the fall cankerworm adults and pear psylla adults are active and breed when temperatures are in the minimum effective range for most other insects; others such as thrips propagate best when temperatures are very high; but the majority of insects fall within the regions designated in the diagram.

The maximum effective temperature range includes temperatures at which insects will continue to live but at which their development will be slowed down because of excessive heat; and the multiplication rate will be lowered because of increased mortality. If temperatures increase beyond this range the insect will die. In the minimum effective temperature range, development is again slowed down because of cool conditions. Thus we may expect to have less trouble from most pests under very hot or very cool conditions and a major amount of trouble when temperatures fall within the optimum effective range.

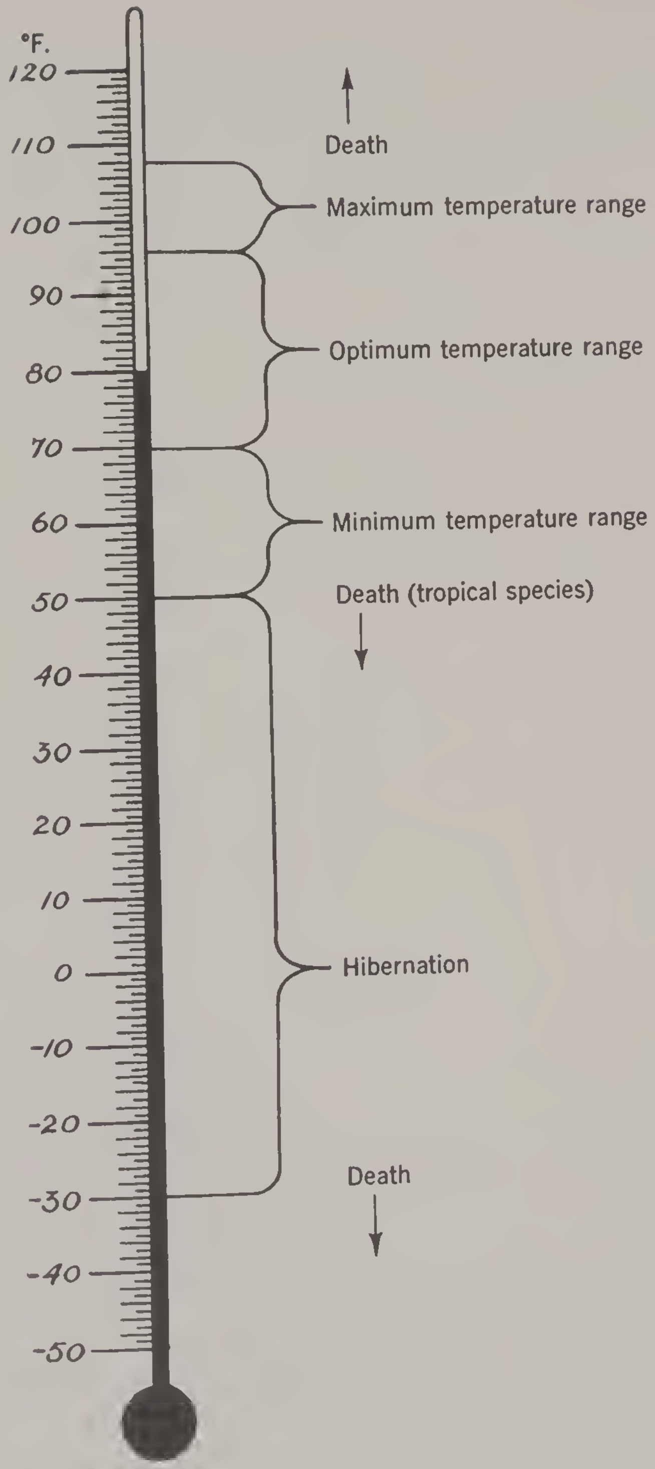

FIG. 22. The relationship between temperature and insect activity in temperate climates.

COLD TEMPERATURES AND INSECTS. Tropical insects die if temperatures drop much below the minimum effective range, but insects of temperate climates go into a dormant stage known as hibernation. It is during hibernation that heavy mortality may occur from freezing or dessication. The ability of insects, like that of plants, to resist freezing is tied up with the undercooling point of the free- and bound-water content of their bodies. The exact subfreezing or undercooling temperature that insects in their hibernating stages may withstand varies with individuals and with different species, probably because of the variable ratio of free to bound water in their body tissues. Severe winters with extremely low temperatures and little snow cover on the ground and winters with many freezes and thaws induce high insect mortalities. Evenly cold winters with much snow greatly increase their survival. A number of insects such as the corn earworm that perish in the winter in the more northerly states overwinter successfully in the southern states and migrate north again in the spring and summer. The cotton leafworm does not have a dormant stage and migrates every summer into the southern cotton regions from points farther south in the tropics. The moths have been found as far north as New York State during the late summer.

EFFECT OF MOISTURE ON INSECTS. In combination with temperature, moisture in both the air and soil also greatly influences the development of insects. A diagram similar to the one for temperature could be drawn indicating optimum, minimum, and maximum humidity ranges for insect groups or stages. Most insect species that attack plants cannot tolerate very low humidities or dry conditions. In the tropics insects go into estivation in response to low humidities and high temperatures. Relative air humidities of from 50 to 80 per cent are probably best for most external plant pests. The plants themselves probably help maintain favorable humidities for most plant pests attacking them internally. High humidities together with normal or high temperatures tend to induce bacterial or fungous disease epidemics among insects. Severe droughts are just as hard on some insect pests as they are on plants. Precipitation in the form of heavy, wind-driven rains is very destructive to small, delicate insects, but in the spring precipitation in the form of warm rains helps bring insects out of hibernation.

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EFFECTS OF SUNLIGHT ON INSECTS. Both the intensity and the duration of sunlight also greatly influence insects. Some insects are active only at night, others are active only during the day; and some insects avoid bright light, although others favor it. The length of daylight has a profound effect on some insect species. Aphids are parthenogenetic and ovoviviparous during the long days of spring and summer, but during the short days of fall males are stimulated to appear, fertilization takes place, and overwintering eggs are laid on the trees.

EXAMPLES OF SOME INSECT LIFE HISTORIES

Mexican Bean Beetle (*Epilachna varivestis*)

Distribution. Ranges over nearly all the Unites States.

Plants Attacked. Beans of all types, cowpeas, soybeans, and *beggar-ticks*. May also feed on other legumes when infestations are heavy and food is scarce.

Injury. Both larvae and adults feed mainly on the undersides of leaves (Figs. 23 and 24). The larvae usually leave the upper epidermis intact. Complete destruction of foliage, pods, and parts of stems follows heavy infestation.

Life History. See Fig. 25. On the average it takes about a month for one complete generation from egg to adult. Adults usually arrive in fields as soon as the first planted beans have their first pair of leaves.

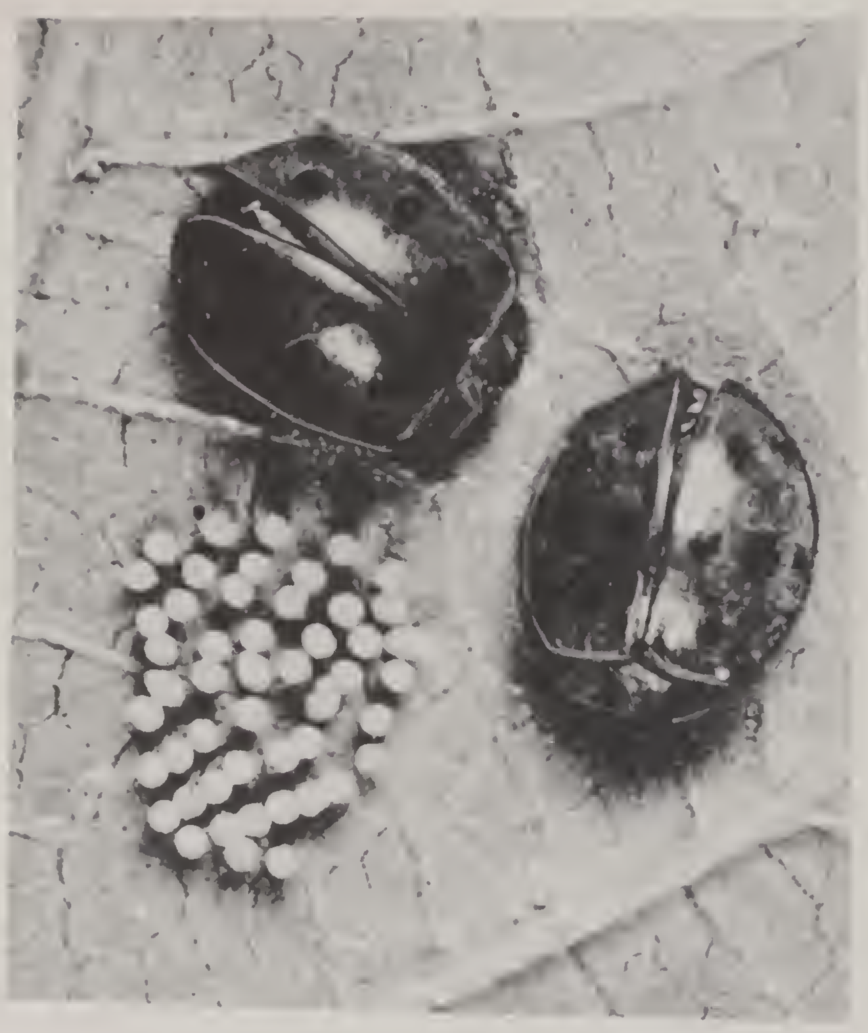


FIG. 23. Mexican bean beetle; adults and eggs on the underside of a leaf.

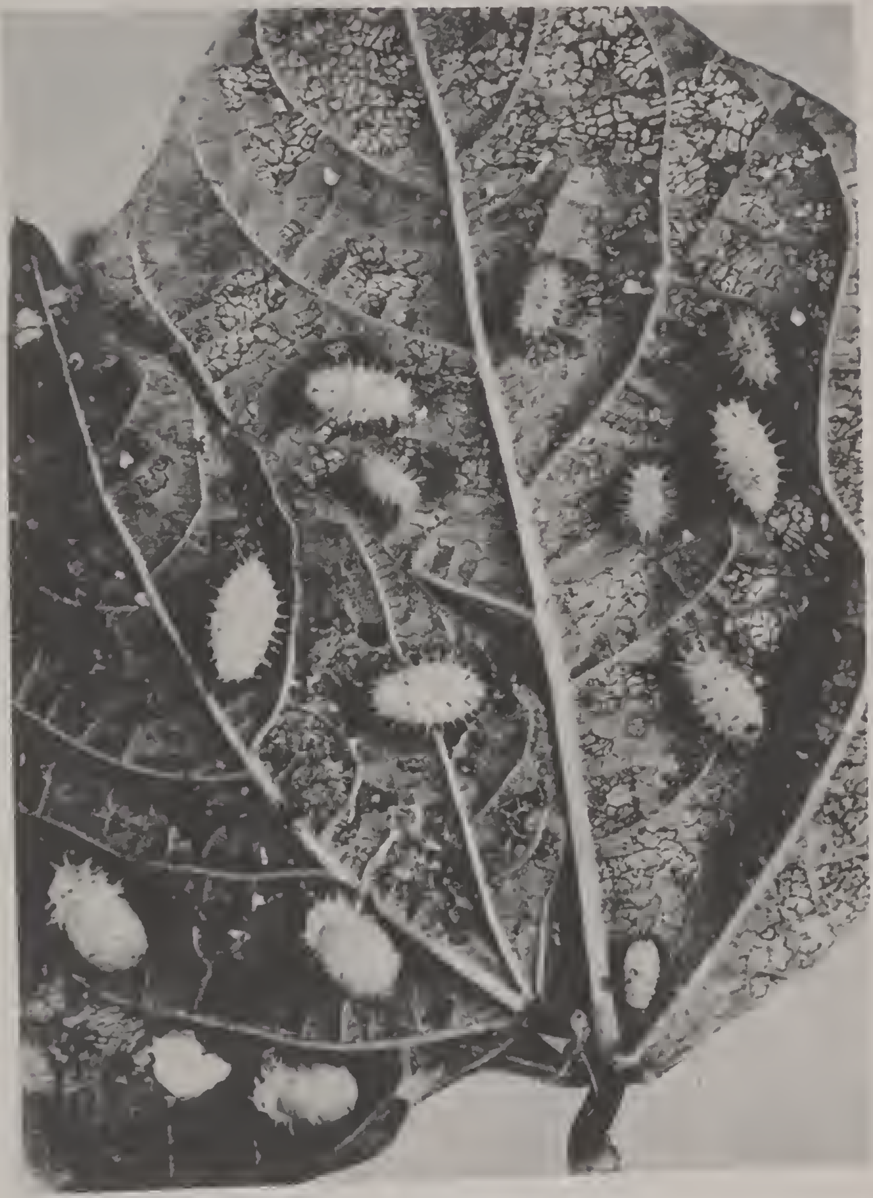


FIG. 24. Mexican bean beetle; larvae, pupae, and injury to leaf.

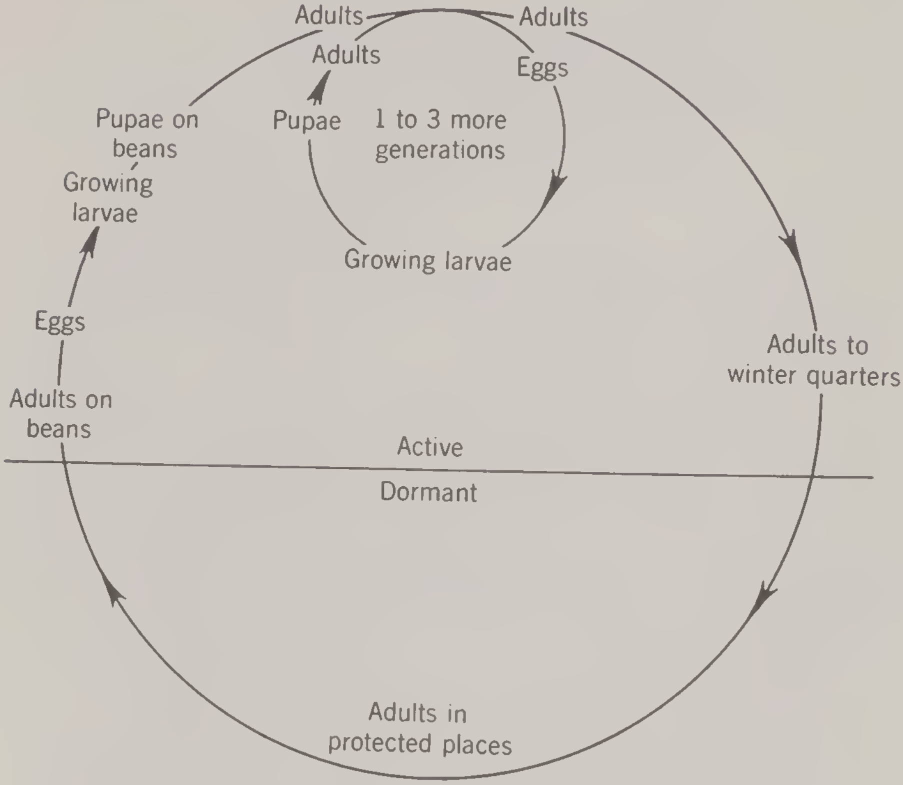


FIG. 25. The seasonal life history of the Mexican bean beetle.

Grasshoppers

Species Concerned. Rocky mountain locust (Melanoplus mexicanus), the differential locust (M. differentialis), the red-legged grasshopper (M. femur-rubrum), and the two-striped grasshopper (M. bivittus).

Distribution. Throughout North America.

Injury. Consume foliage and other green plant parts.

Life History. See Figs. 26 and 27. In some of the less important species the eggs hatch in the early fall and the young nymphs hibernate.

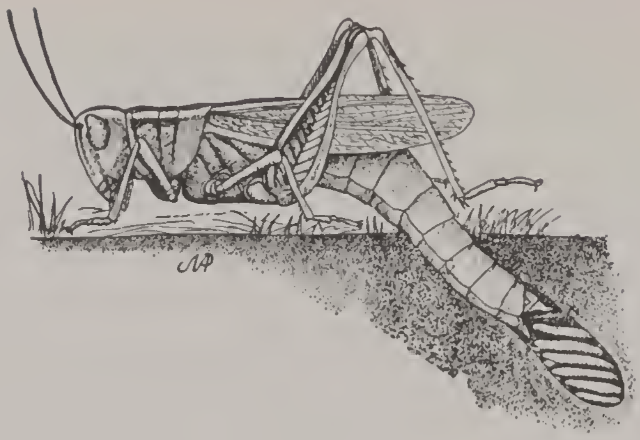


FIG. 26. Grasshopper laying eggs in the ground (from Col. Agr. Expt. Sta. Circ. 89-A).

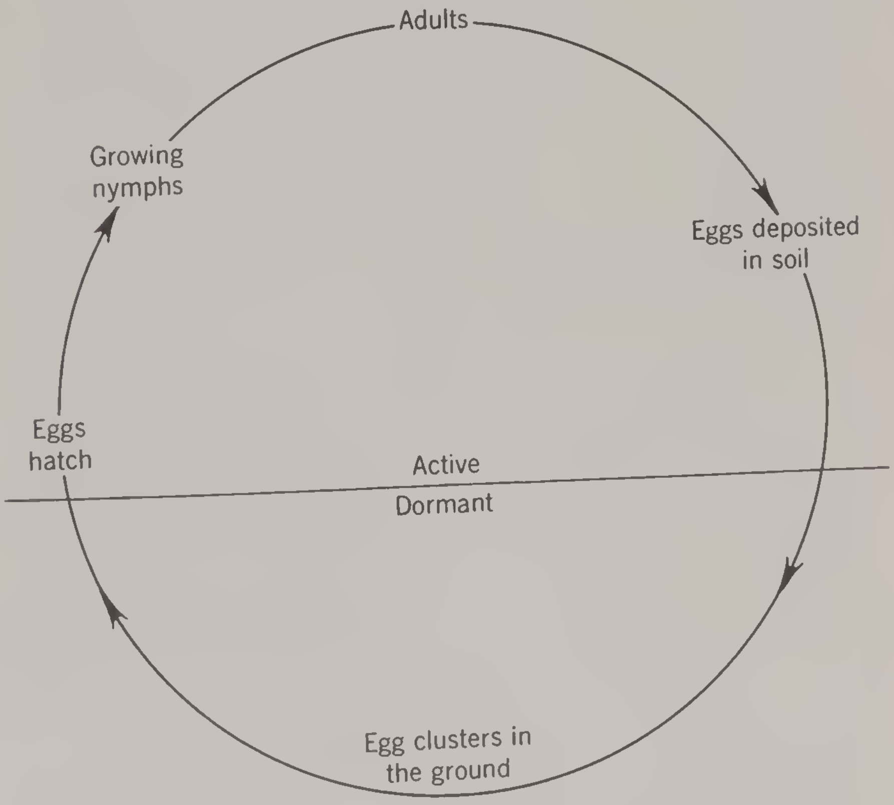


FIG. 27. The life history of the differential locust.

Rosy Apple Aphid (Anuraphis roseus)

Distribution. General throughout the United States and Canada in the apple-growing regions.

Plants Attacked. Apple, pear, thorn, and Sorbus. Narrow-leaved plantain is alternate host for some generations during the summer.

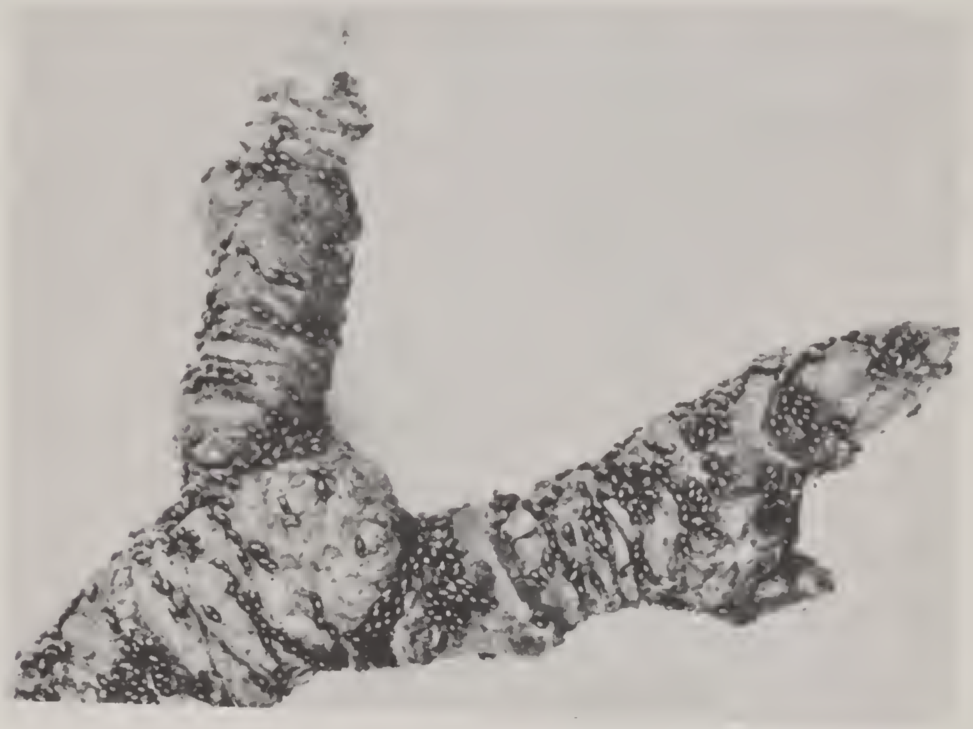


FIG. 28. Aphid eggs on an apple twig.

Injury. Cause leaves to curl, stunt growth; apples remain small and malformed. Aphids excrete honeydew on which a sooty mold fungus grows.

Life History. See Figs. 28, 29, 30 and 31. About one generation is completed every 2 weeks in warm weather.

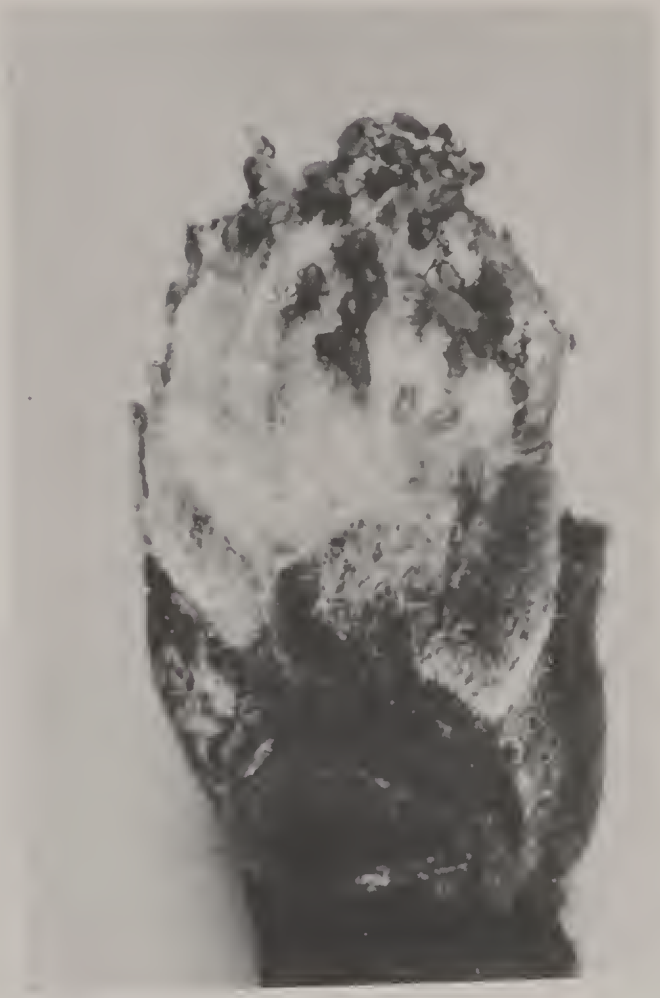


FIG. 29. Newly hatched aphids on an apple bud in the green-tip stage of development.

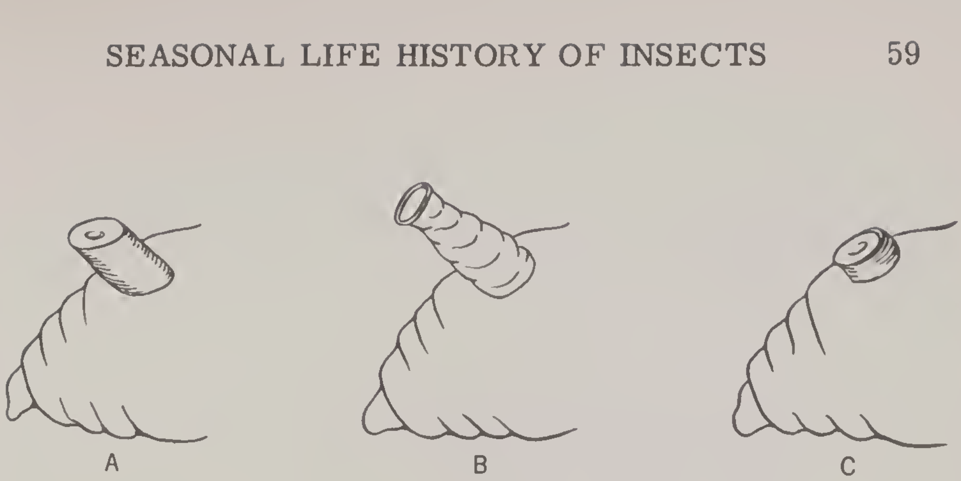


FIG. 30. The cornicles of three species of newly hatched aphids on apples. A, green apple aphid; B, rosy apple aphid; C, grain aphid (redrawn with modifications from Mills and Dewey, Cornell Ext. Bull. 711).

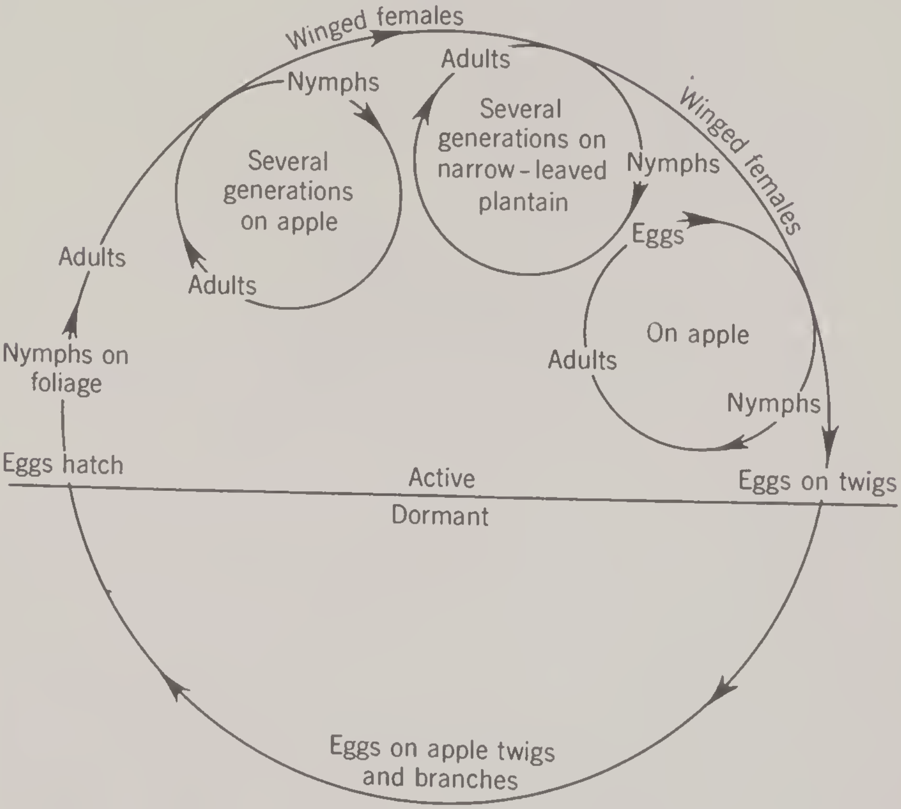


FIG. 31. The life history of the rosy apple aphid.

San Jose Scale (Aspidiotus perniciosus)

Distribution. Throughout the United States and Canada where fruits are grown.

Plants Attacked. Most fruit and some shade and forest trees.

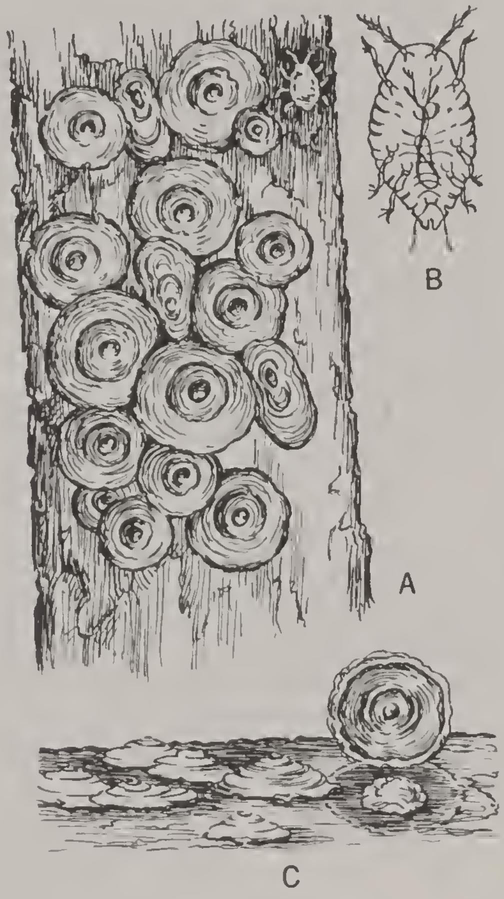


FIG. 32. San Jose scale. A, scales on limb; B, "crawler" enlarged; C, scale lifted to show insect underneath (redrawn from Quaintance, U. S. Dept. Agr. Farmers' Bull. 650).

Injury. Sucking either weakens or kills plants or plant parts, or it disfigures and discolors fruits. Infested trees decrease in vigor, and foliage becomes thin and yellowed from presence of scales upon it. Fruit often with small, red, inflamed areas surrounding each scale.

Life History. See Figs. 32 and 33. Many scale species overwinter in the egg stage. Scales in tropical regions breed continuously. In San Jose scale there is an overlapping of generations, because females produce living young for about a month.

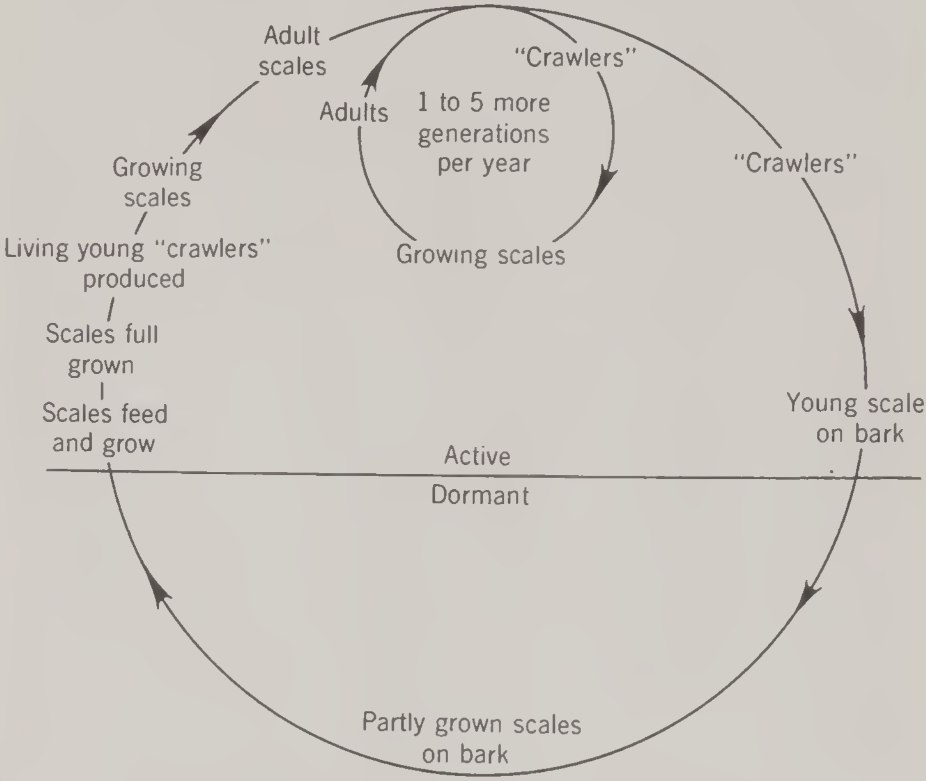


FIG. 33. The life history of the San Jose scale (Aspidiotus perniciosus).

Onion Thrips (Thrips tabaci)

Distribution. Throughout the United States and Canada.

Plants Attacked. Onions, nearly all other garden crops, also many weeds, ornamental flowers, and some field crops.

Injury. By rasping foliage and sucking sap they produce grayish mottling of foliage which later may become distorted, turn rusty, and drop off or fall over. Plants may be killed or severly stunted (Fig. 34).

Life History. See Figs. 35 and 36. Generations overlap each other so that all stages are generally found on plants at the same time.

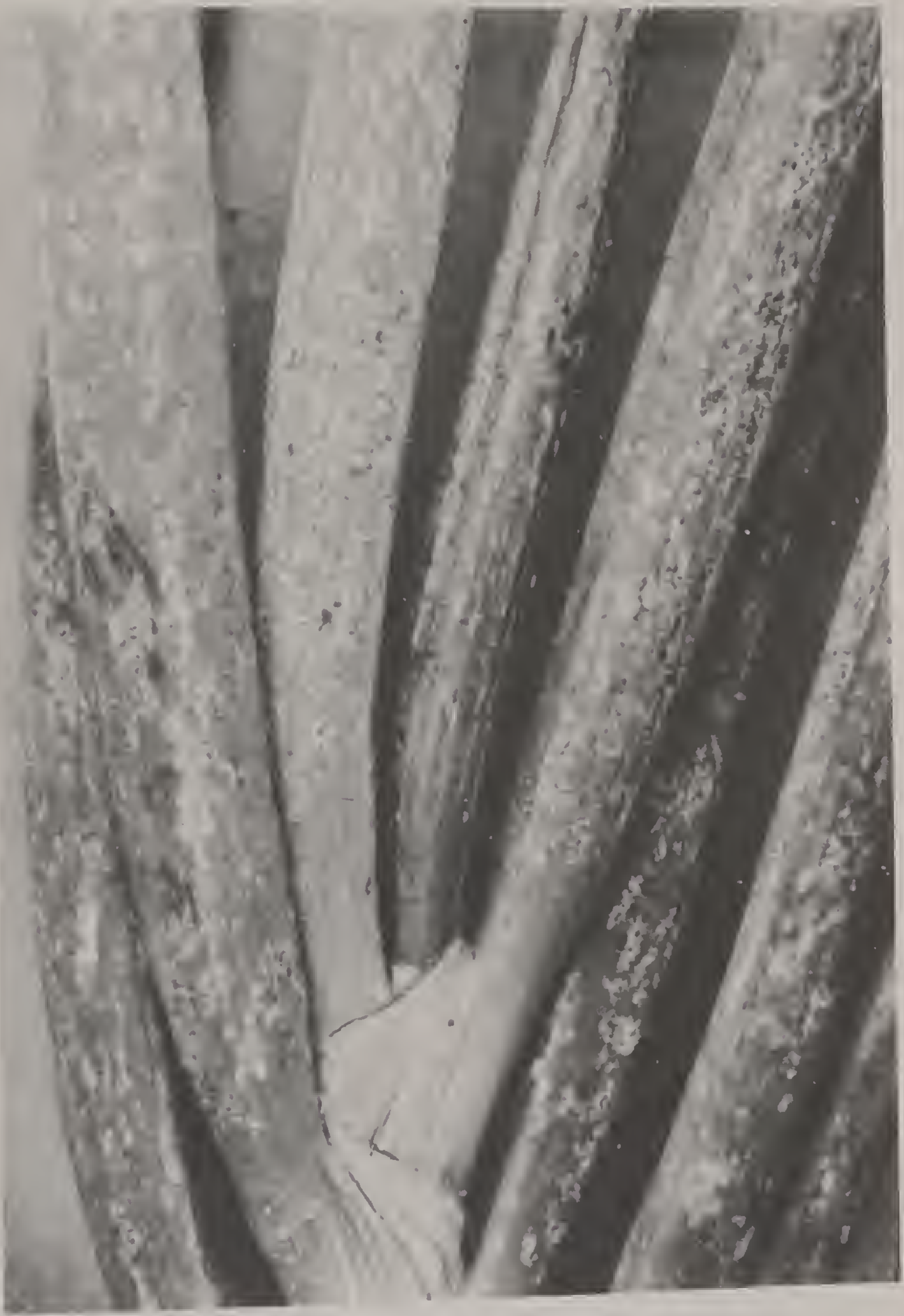


FIG. 34. Onion thrips injury on onion foliage.

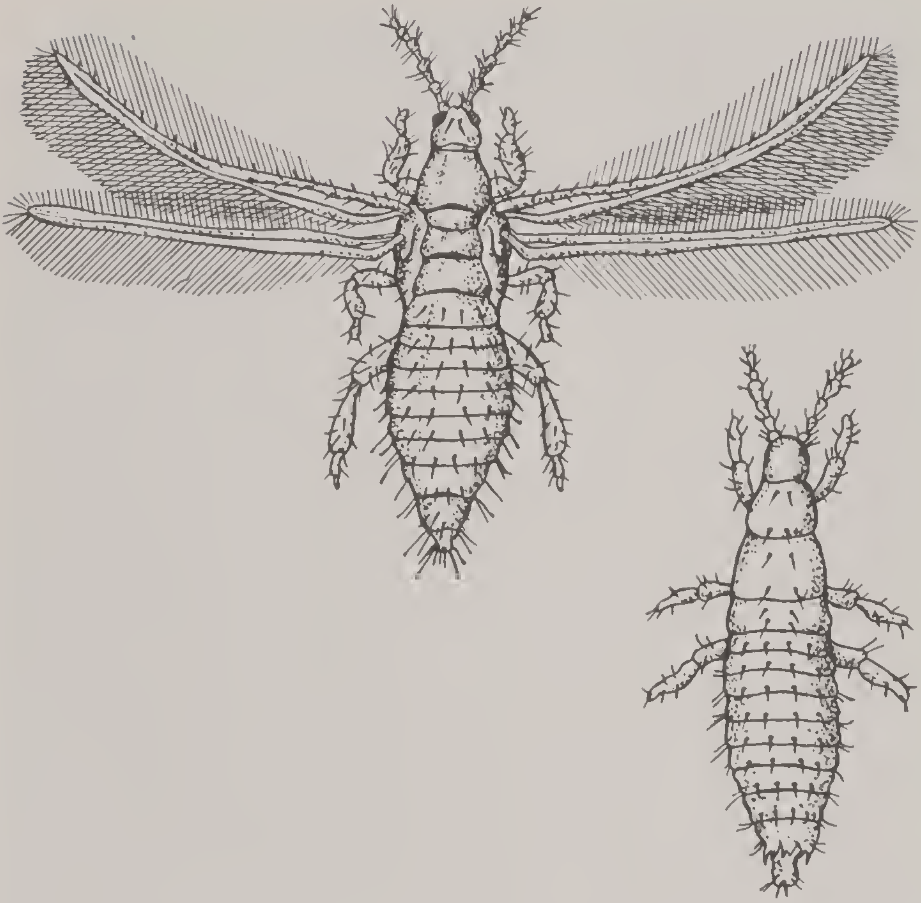


FIG. 35. Adult and nymph of a thrips greatly enlarged (redrawn from Moulton, U.S. Dept. Agr. Dept. Bull. 173).

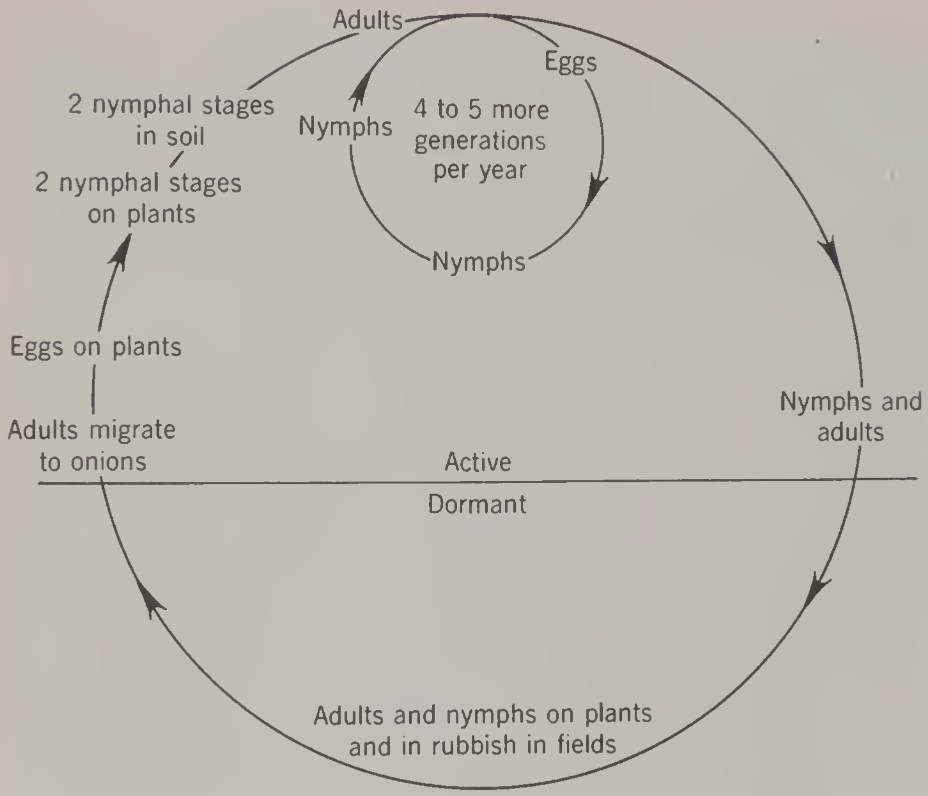


FIG. 36. The life history of the onion thrips (Thrips tabaci).

Peach Tree Borer (Sanninoidea exitiosa)

Distribution. Throughout the United States and British Columbia.

Plants Attacked. Peach, wild and cultivated cherry, plum, prune, nectarine, apricot, almond, and some ornamentals of the genus Prunus.

Injury. Larvae feed on inner bark and cambium above and below soil line. May completely girdle trees and kill them or weaken them and make them unproductive. Attack characterized by masses of gum mixed with frass from trunks near soil line (Fig. 37).

Life History. See Fig. 38. The California peach tree borer (Conopia opalesceus) has a similar life history. Some larvae do not pupate until the second summer.

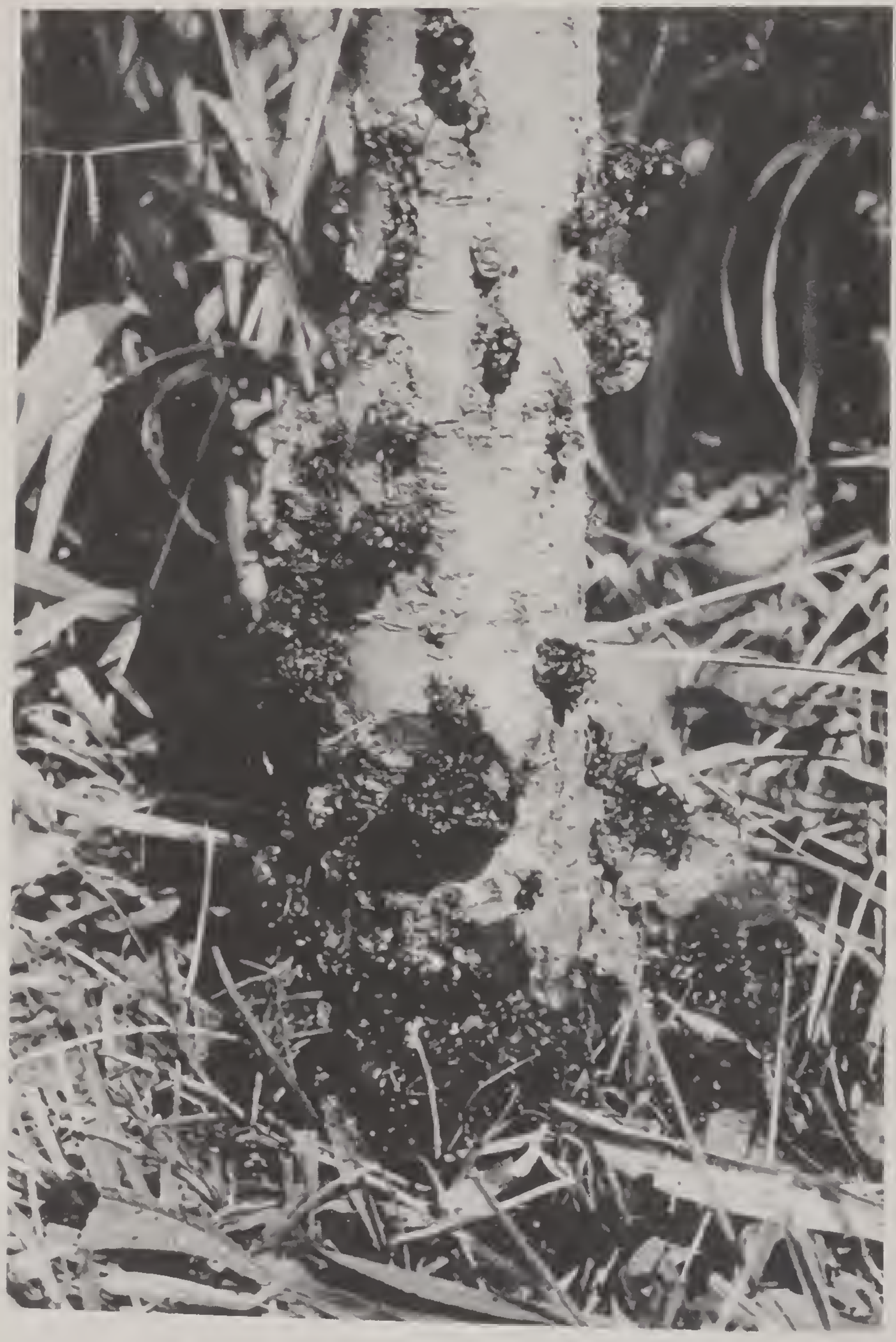


FIG. 37. Peach tree borer injury.

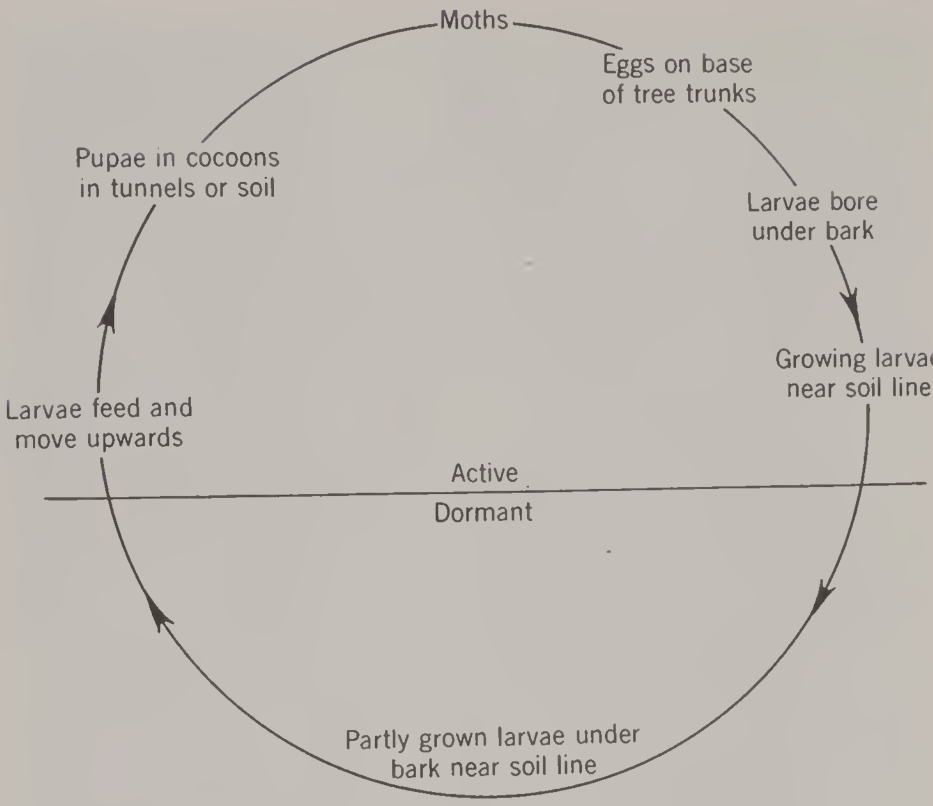

Moths
Eggs on base of tree trunks
Larvae bore under bark
Growing larvae near soil line
Active
Dormant
Partly grown larvae under bark near soil line
Larvae feed and move upwards
Pupae in cocoons in tunnels or soil

FIG. 38. The life history of the peach tree borer (Sanninoidea exitiosa).

European Corn Borer (Pyrausta nubilalis)

Distribution. Over most of the eastern corn-growing areas of North America as far west as Iowa.

Plants Attacked. Most herbaceous stemmed plants large enough for the larvae to tunnel into. Preferred hosts are corn, dahlias, gladioli, and weeds such as dock, cocklebur, pigweed, and smartweed. More than 200 host plants known.

Injury. Larvae bore into stems and branches, weakening them and causing them to wilt or break over. On corn they attack the ear shanks, causing the ears to drop off, and also attack ears, reducing the crop. Sweet corn is made unsalable.

Life History. See Figs. 39 and 40. One or two generations a year depending on the region.

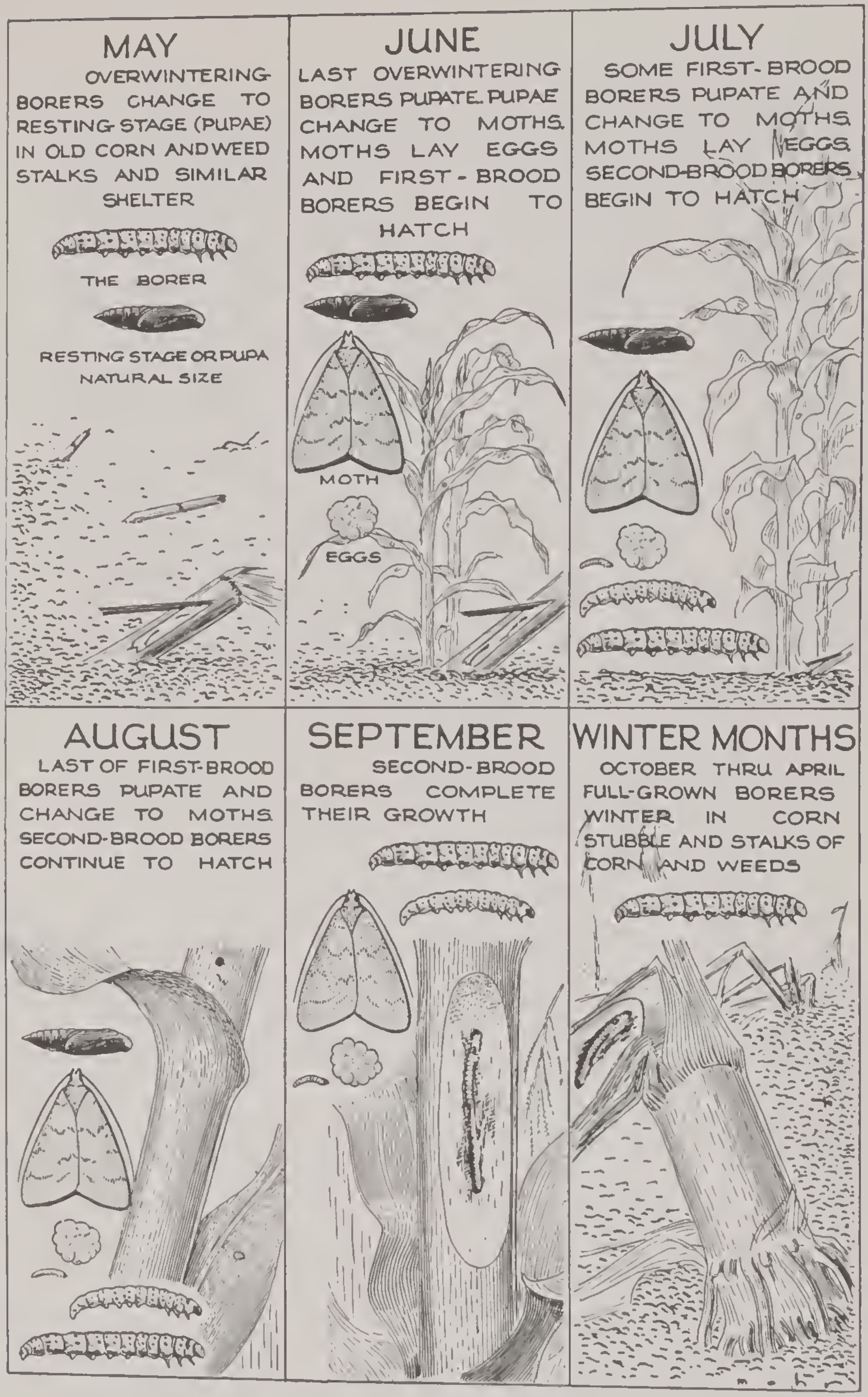

MAY
OVERWINTERING BORERS CHANGE TO RESTING STAGE (PUPAE) IN OLD CORN AND WEED STALKS AND SIMILAR SHELTER
THE BORER
RESTING STAGE OR PUPA NATURAL SIZE
JUNE
LAST OVERWINTERING BORERS PUPATE. PUPAE CHANGE TO MOTHS. MOTHS LAY EGGS AND FIRST-BROOD BORERS BEGIN TO HATCH
MOTH
EGGS
JULY
SOME FIRST-BROOD BORERS PUPATE AND CHANGE TO MOTHS. MOTHS LAY EGGS. SECOND-BROOD BORERS BEGIN TO HATCH
AUGUST
LAST OF FIRST-BROOD BORERS PUPATE AND CHANGE TO MOTHS. SECOND-BROOD BORERS CONTINUE TO HATCH
SEPTEMBER
SECOND-BROOD BORERS COMPLETE THEIR GROWTH
WINTER MONTHS
OCTOBER THRU APRIL FULL-GROWN BORERS WINTER IN CORN STUBBLE AND STALKS OF CORN AND WEEDS

FIG. 39. The life history of the European corn borer (Pyrausta nubilalis) (from Univ. of Ill. Circ. 637).

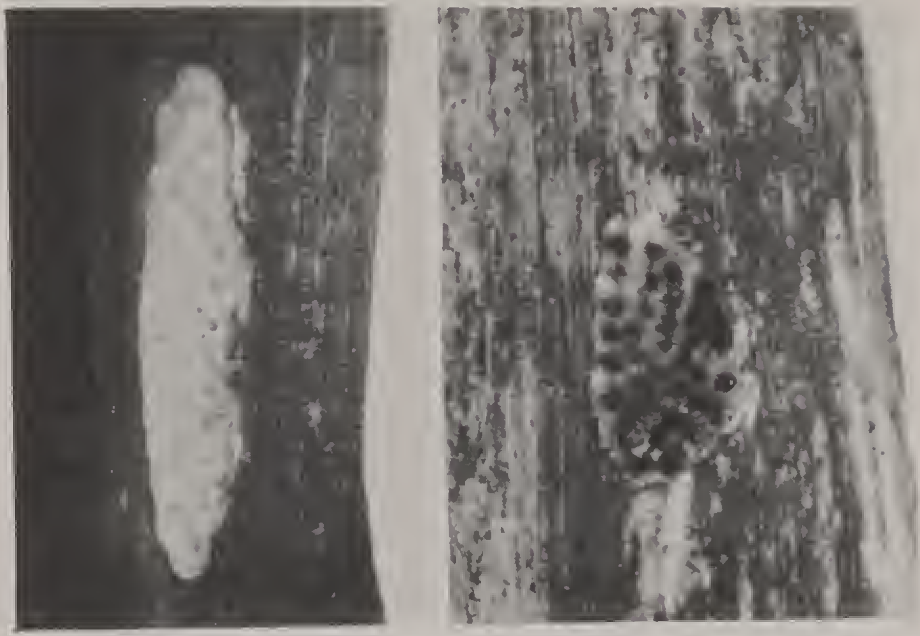


FIG. 40. European corn borer eggs. A, newly laid egg mass; B, egg mass about to hatch.

Codling Moth (Carpocapsa pomonella)

Distribution. Throughout apple-growing regions of North America.

Plants Attacked. Fruit of apple, pear, quince, English walnut, wild haw, and crab apples.

Injury. Larvae are the cause of "wormy" fruit or seeds and of premature dropping of fruit.

Life History. See Figs. 41 and 42.

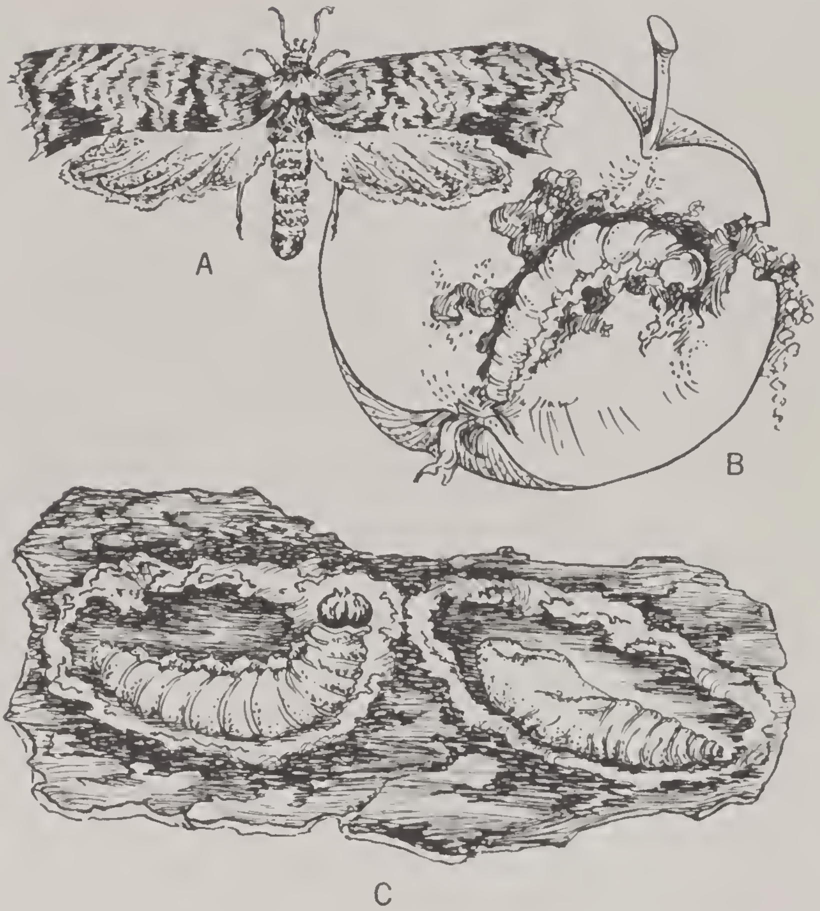


FIG. 41. Codling moth. A, adult; B, larva in apple; C, larva and pupa in hibernating cells under bark.

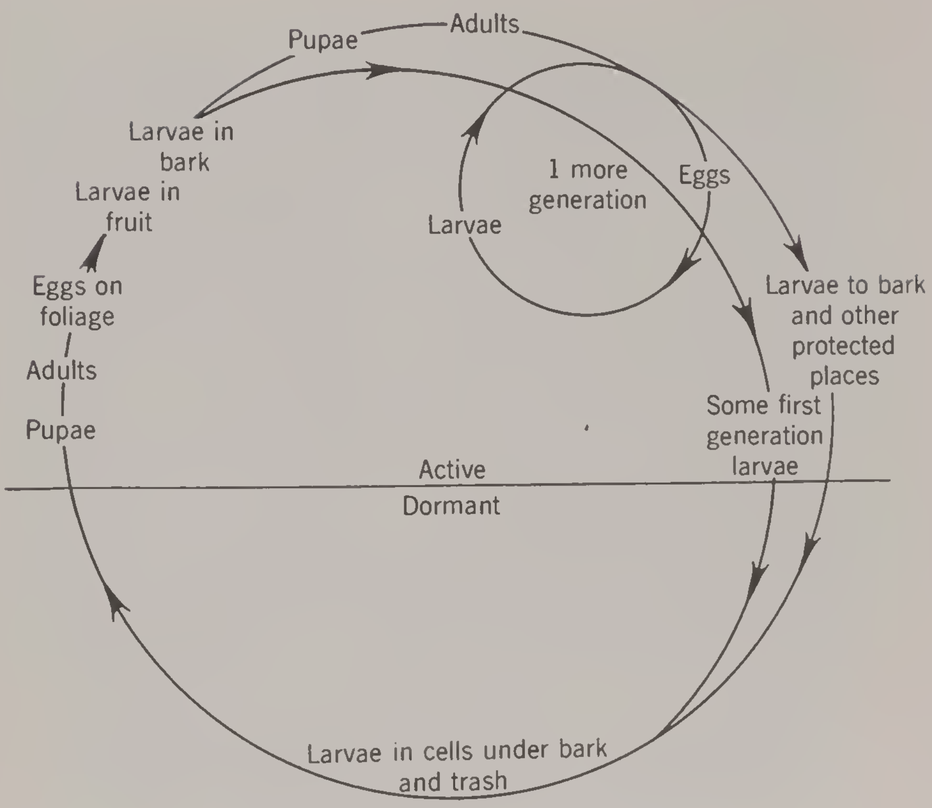


FIG. 42. The life history of the codling moth (Carpocapsa pomonella).

Japanese Beetle (Popillia japonica)

Distribution. Throughout eastern United States and in isolated colonies west to Missouri.

Plants Attacked. Larvae feed on roots of grasses and of many other plants. Adults feed on foliage and fruit of most deciduous plants including many weeds.

Injury. Larvae feeding on grass and vegetable roots destroy the plants (Fig. 43). Produce dead areas in lawns. Adults defoliate susceptible trees, shrubs, and herbaceous plants, also destroy ripening fruit. Larval stage of other white grubs may extend up to 3 years.

Life History. See Fig. 44.

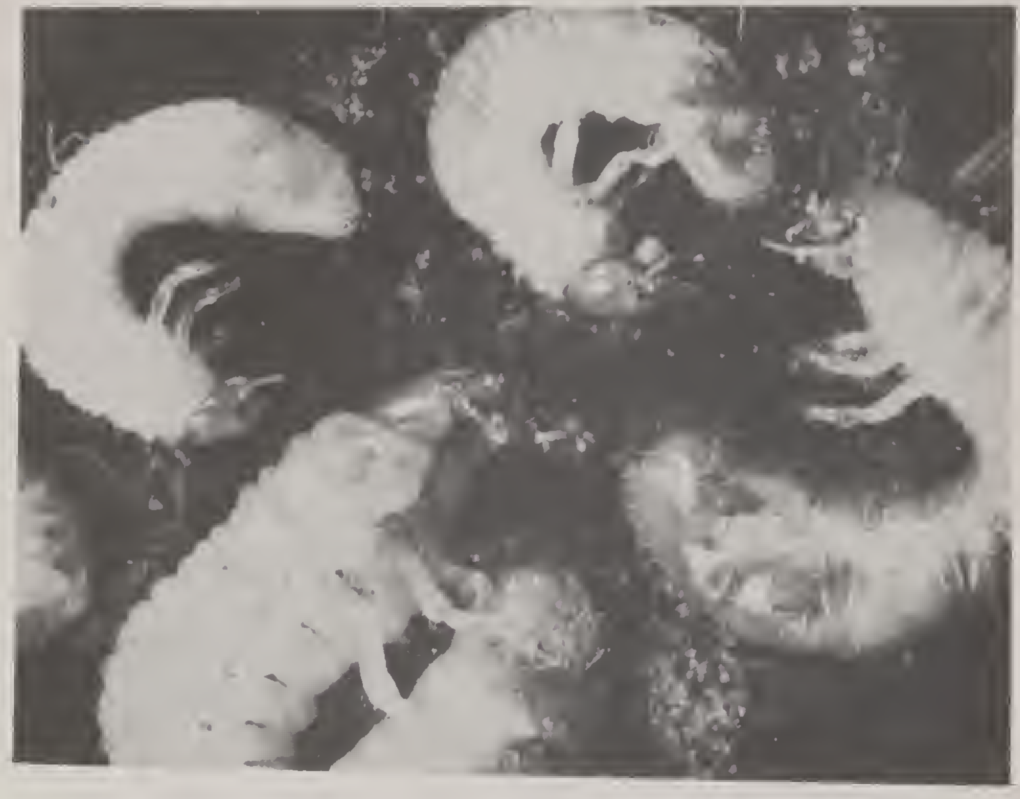


FIG. 43. Various species of beetle grubs in the soil.

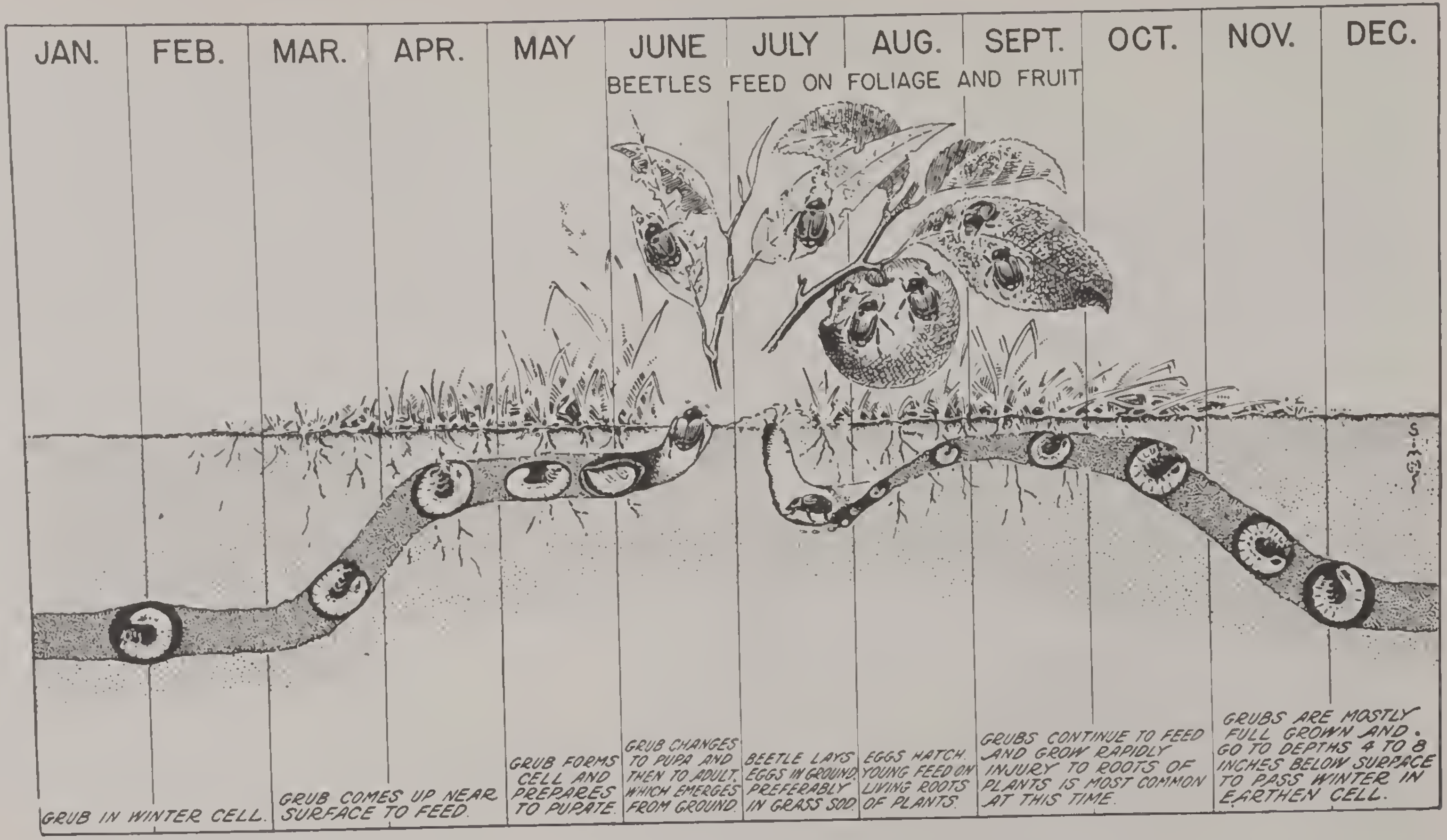

JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
BEETLES FEED ON FOLIAGE AND FRUIT
GRUB IN WINTER CELL.
GRUB COMES UP NEAR SURFACE TO FEED.
GRUB FORMS CELL AND PREPARES TO PUPATE.
GRUB CHANGES TO PUPA AND THEN TO ADULT, WHICH EMERGES FROM GROUND.
BEETLE LAYS EGGS IN GROUND, PREFERABLY IN GRASS SOD.
EGGS HATCH. YOUNG FEED ON LIVING ROOTS OF PLANTS.
GRUBS CONTINUE TO FEED AND GROW RAPIDLY. INJURY TO ROOTS OF PLANTS IS MOST COMMON AT THIS TIME.
GRUBS ARE MOSTLY FULL GROWN AND GO TO DEPTHS 4 TO 8 INCHES BELOW SURFACE TO PASS WINTER IN EARTHEN CELL.

FIG. 14. The life history of the Japanese beetle (U. S. Dept. Agr. Japanese Beetle Laboratory).

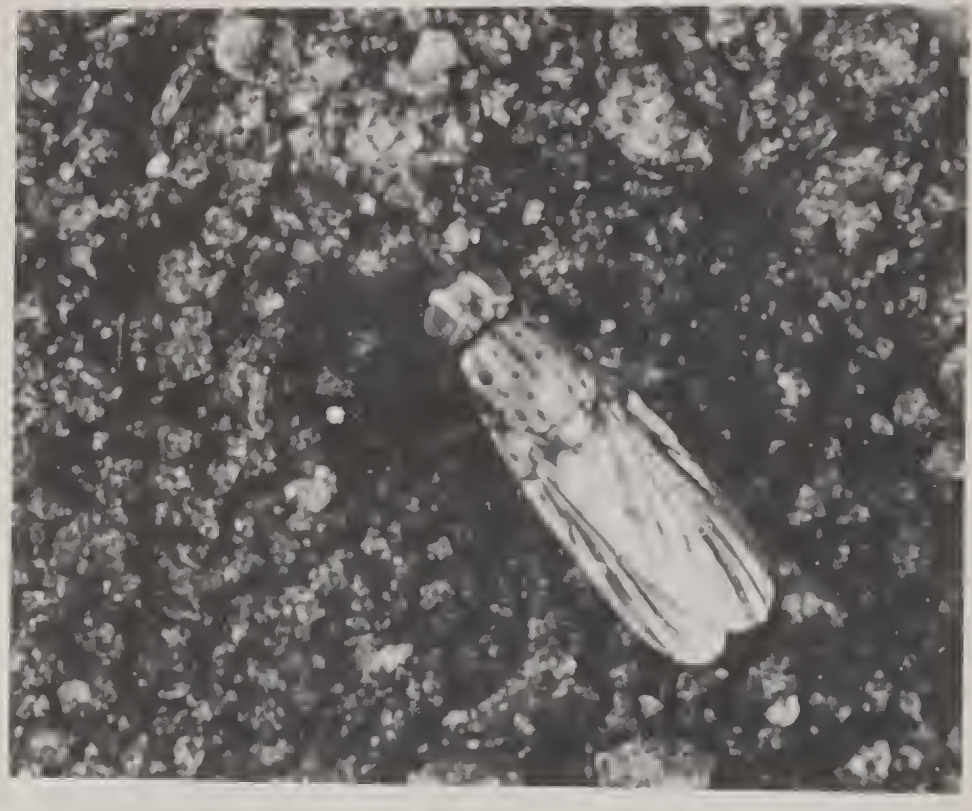


FIG. 45. Cabbage maggot fly.

Cabbage Maggot (Hylemya brassicae)

Distribution. Northern United States and Canada.

Plants Attacked. All cruciferous plants such as cabbage, cauliflower, radish, turnip, and weeds belonging to the mustard group.

Injury. Maggots feed on small fibrous roots and bore into larger ones. Plants stop growth, appear sickly, wilt in sun, and usually die or produce no crop.

Life History. See Figs. 45 and 46. Onion maggot and seed corn maggot have similar life histories.

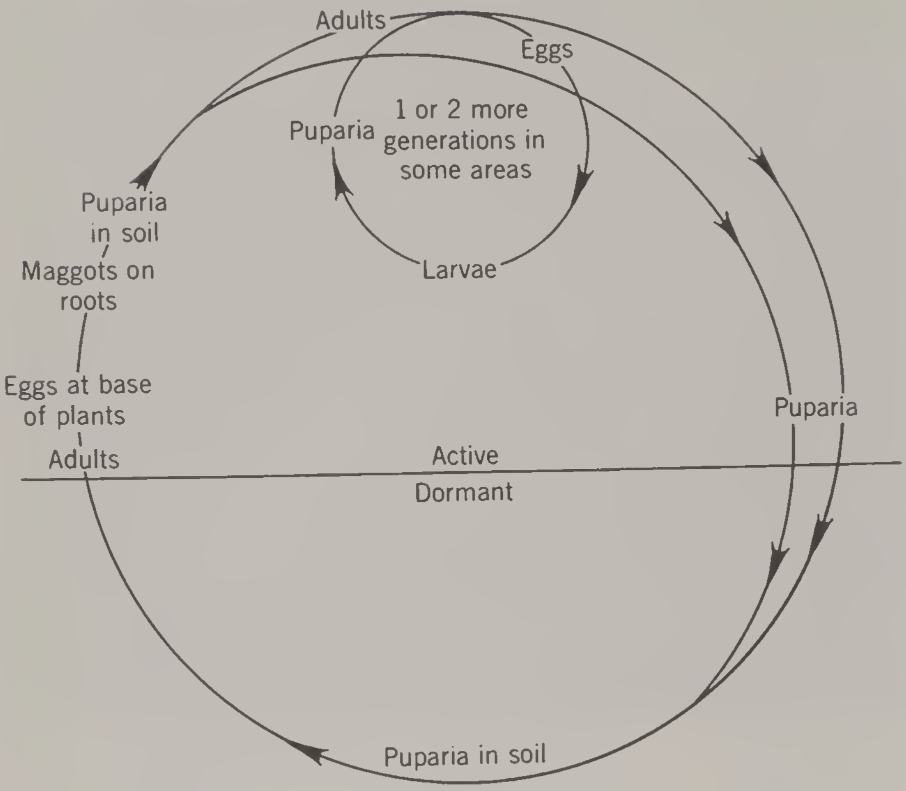


FIG. 46. The life history of the cabbage maggot (Hylemya brassicae).

Wireworms (Family Elateridae)

Distribution. Throughout North America.

Plants Attacked. Roots of most plants in the grass family, such as corn and wheat; also clovers, beans, potatoes, and beets.

Injury. Attack planted seed and prevent germination; feed on roots and tubers, often boring into them or into the underground parts of plant stalks, killing young plants.

Life History. See Figs. 47 and 48. Life history varies in different species from 2 to 6 years.

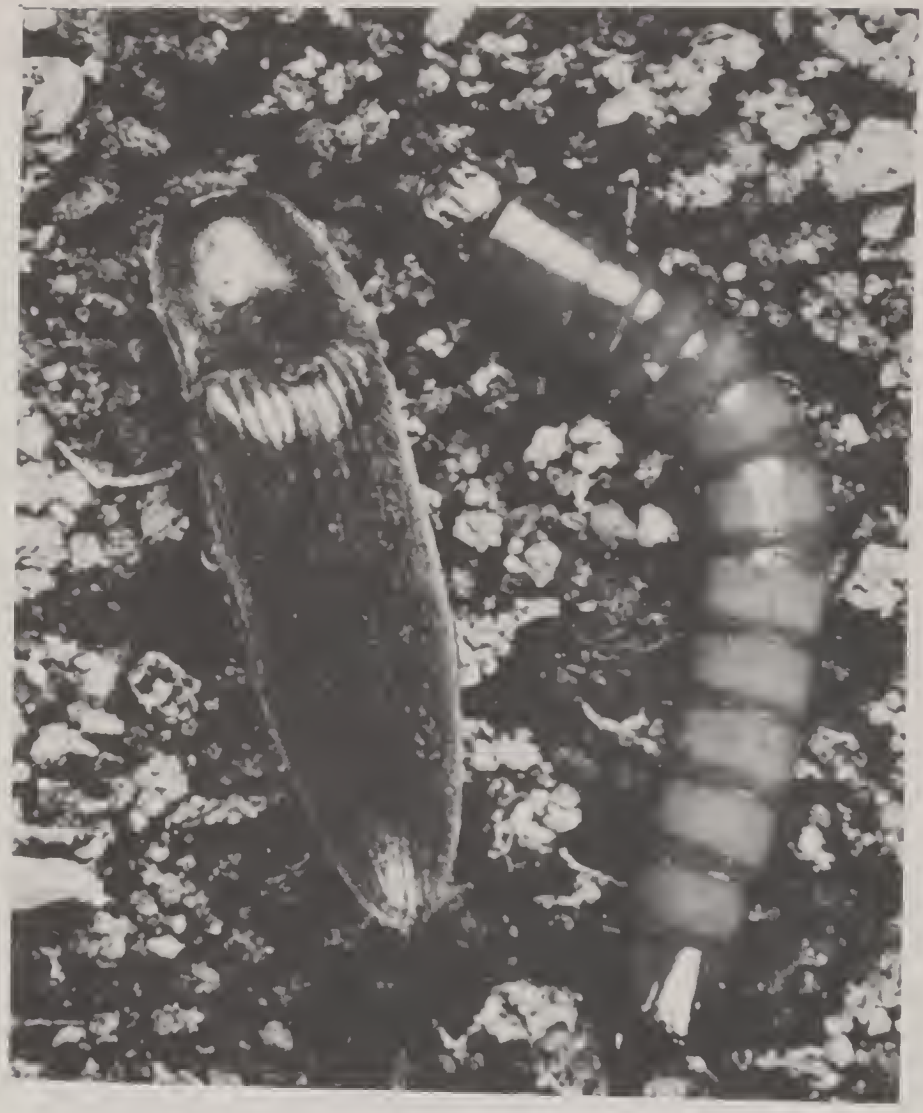


FIG. 47. Wireworm and adult click beetle.

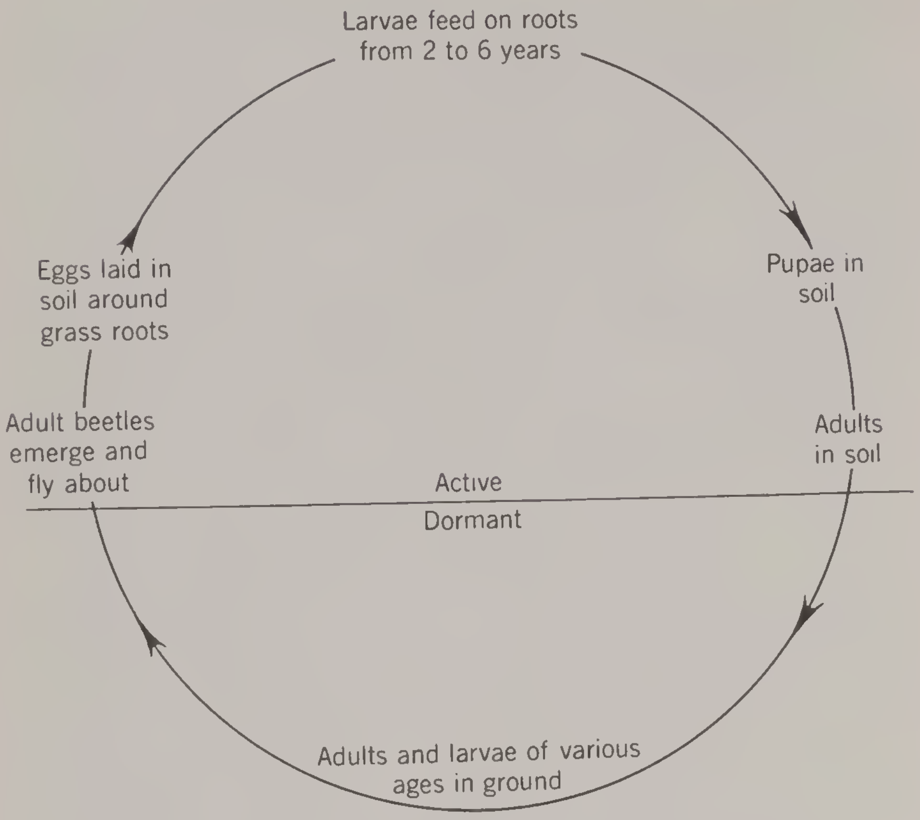

Larvae feed on roots from 2 to 6 years
Pupae in soil
Adults in soil
Active
Dormant
Adults and larvae of various ages in ground
Adult beetles emerge and fly about
Eggs laid in soil around grass roots

FIG. 48. The generalized life history of wireworms (Elateridae).

TABLE 1

SOME IMPORTANT PESTS THAT CHEW OFF EXTERNAL PLANT PARTS

Insect	Scientific Name	Host Plants
Blister beetles	Meloidae family	General feeders
Cabbage worms	*Pieris* spp.	Crucifers
Cankerworms	Geometridae family	Deciduous trees and shrubs
Colorado potato beetle	*Leptinotarsa decemlineata*	Potatoes, eggplants, tomatoes
Cotton leafworm	*Alabama argillacea*	Cotton

Table 1 (Continued)

Insect	Scientific Name	Host Plants
Crickets	Gryllidae family	Grasses, grains, other plants and plant products
Cucumber beetles	*Diabrotica* spp.	Cucurbit family and some flowers
Cutworms	Noctuidae family	Nearly all herbaceous plants
Eastern tent caterpillar	*Malacosoma americana*	Apple, peach, plum, cherry, prune
Fall armyworm	*Laphygma frugiperda*	Grasses, grains, vegetables, legumes, cotton, tobacco
Flea beetles	Chrysomelidae family	Vegetables, flowers, some fruits
Gypsy moth	*Porthetria dispar*	General feeder on deciduous trees
Japanese beetle	*Popillia japonica*	General feeder
Leaf rollers	Tortricidae family	Deciduous fruits and many ornamentals
Mexican bean beetle	*Epilachna varivestis*	Beans and other legumes
Webworms	Arctiidae family	Many deciduous and evergreen plants

TABLE 2

SOME IMPORTANT PESTS THAT SUCK ON PLANT PARTS

Insect	Scientific Name	Host Plants
Aphids	Aphididae family	Nearly all plant species
Chinch bug	*Blissus* spp.	Grass family, corn, grains
Harlequin bug	*Murgantia histrionica*	Cruciferous plants, many garden crops, fruits, weeds
Lace bugs	Tingidae family	Foliage of many trees and shrubs
Leafhoppers	Cicadellidae family	Numerous trees, shrubs, vegetables, flowers
Mealy bugs	*Pseudococcus* spp.	All citrus, many ornamental and greenhouse plants
Psyllids	Psyllidae (*Chermidae*) family	Pear, boxwood, broad-leaved evergreens, many trees
Scale insects	Coccidae family	Numerous trees, shrubs, perennial greenhouse ornamentals
Spittle bugs	Cercopidae family	Grasses, legumes, trees, some fruits
Squash bug	*Anasa tristis*	Cucurbits
Tarnished plant bug, etc.	*Lygus* spp.	Many species of trees and herbaceous plants; alfalfa seed production reduced
Thrips	Thysanoptera order	Citrus, many deciduous trees, fruits, ornamentals, greenhouse crops
Treehoppers	Membracidae family	Numerous woody trees, shrubs
White flies	Aleyrodidae family	Various tropical and greenhouse plants, laurel, rhododendron, honeysuckle, etc.

TABLE 3

SOME IMPORTANT BORERS

Fruit, Nut, Seed, and Bud Borers

Insect	Scientific Name	Host Plants
Apple maggot	Rhagoletis pomonella	Apples, blueberries, wild crabs, haws
Boll weevil	Anthonomus grandis	Cotton
Clover seed midge	Dasyneura leguminicola	Red clover
Corn earworm or tomato fruitworm	Heliothis armigera	Corn, tomato, tobacco, cotton, etc.
Oriental fruit moth	Grapholitha molesta	Peach, quince, apple, pear, apricot, plum, etc.
Pickle and melon worms	Diaphania spp.	Most cucurbits
Pink bollworm	Pectinophora gossypiella	Cotton
Plum curculio	Conotrachelus nenuphar	Most pome and stone fruits
Spruce budworm	Choristoneura fumiferana	Spruce and balsam

Wood Borers

Insect	Scientific Name	Host Plants
Bark beetles	Scolytidae family	Many evergreen and deciduous trees
Carpenterworm	Prionoxystus robiniae	Oaks, maple, cottonwood, willow, chestnut
Flat headed borers	Buprestidae family	Many evergreen and deciduous trees
Leopard moth	Zeuzera pyrina	Elms, maples, etc.
Round headed borers	Cerambycidae family	Some shade and forest trees
White-pine weevil	Pissodes strobi	Pines and spruce

Table 3 (Continued)

Herbaceous Plant Borers

Insect	Scientific Name	Host Plants
Corn billbugs	Calendra spp.	Corn, rice, large swamp grasses
Hessian fly	Phytophaga destructor	Wheat
Squash vine borer	Melittia cucurbitae	Squashes, at times other cucurbits
Stalk borer	Papaipema nebris	Most herbaceous plants
Sugarcane borer	Diatraea saccharalis	Sugarcane, corn, rice
Wheat stem maggot	Meromyza americana	Small grains, bluegrass, other grasses
Wheat stem sawfly	Cephus cinctus	Small grains, some native grasses

Leaf Miners

Insect	Scientific Name	Host Plants
Apple leaf trumpet miner	Tischeria malifoliella	Apples
Birch leaf miner	Fenusa pusilla	Birch
Boxwood leaf miner	Monarthropalpus buxi	Boxwood
Chrysanthemum leaf miner	Phytomyza chrysanthemi	Chrysanthemums, Cineraria
Holly leaf miner	Phytomyza ilicis	Holly
Locust leaf miner	Chalepus dorsalis	Black locust
Spinach leaf miner	Pegomyia hyoscyami	Spinach, beets, Swiss chard

TABLE 4

SOME IMPORTANT SUBTERRANEAN PESTS

Insect	Scientific Name	Host Plants
Billbugs	*Calendra* spp.	Corn, grasses, grains, peanuts
Black vine weevil	*Brachyrhinus sulcatus*	Cylamen, begonia, yews, azalea
Corn root aphid	*Anuraphis maidi-radicis*	Corn, cotton, some grasses, weeds
Corn rootworms	*Diabrotica* spp.	Corn, grasses, many cultivated crops
Onion maggot	*Hylemya antiqua*	Onions
Seed-corn maggot	*H. cilicrura*	Seed of corn, beans, Lima beans, etc.
Strawberry rootworm	Chrysomelidae family	Strawberry, raspberry, grape, rose
Western grape rootworm	*Adoxus obscurus*	Grapes and related plants
White-fringed beetle	*Naupactus leucoloma*	Peanuts, corn, sugar cane, cotton, cabbage, sweet potatoes, etc.
White grubs	Scarabaeidae family	Grasses, many vegetables
Woolly apple aphid	*Eriosoma lanigerum*	Apple, pear, hawthorne, elm, mountain ash

TABLE 5

SOME IMPORTANT GALL-FORMING INSECTS

Insect	Scientific Name	Host Plants
Blackberry knot gall	*Diastrophus turgidus*	Blackberry
Chrysanthemum gall midge	*Diarthronomyia hypogaea*	Greenhouse chrysanthemums
Cockscomb elm gall	*Colopha ulmicola*	Elm

Table 5 (Continued)

Insect	Scientific Name	Host Plants
Grape phylloxera	*Phylloxera vitifoliae*	Grape
Horned oak gall	*Plagiotrochus cornigerus*	Pin oak
Red-necked cane borer	*Agrilis ruficollis*	Raspberry, blackberry, dewberry
Spruce gall aphid	*Adelges* spp.	Norway spruce, blue spruces

QUESTIONS FOR DISCUSSION

1. Of what importance is it to a grower to know the life history of his crop pests?
2. What factors would lead to the presence of all stages of an insect on a plant at the same time?
3. Which pest would be easier to control: one that has definite broods with little overlapping of stages or one in which there is so much overlapping of stages that no definite broods can be recognized?
4. Present reasons why most northern insects don't freeze to death in the winter even though temperatures drop far below freezing.
5. What factors operate to produce hibernation? Estivation?
6. Would you expect an insect to have the same number of generations in northern states as in southern states?
7. Since insects are cold-blooded, why aren't temperatures that are optimum for one optimum for all?
8. What are the differences between the incubation of chicken eggs and of insect eggs?
9. Tropical or greenhouse insects fail to survive freezing temperatures. Why?
10. Is dormancy in plants similar to hibernation in insects? Give reasons.
11. What conditions produce high insect mortality in the summer? In the winter?

12. Where do insects that live in dry food products get their moisture?

13. What insects tend to flourish during wet seasons? Dry seasons?

14. How does light regulate insect activities?

15. Study each of the life histories presented in this chapter and pick out the possible points where each pest may be attacked.

16. Why is accurate timing of control measures dependent on a knowledge of the life history of a pest?

17. Discuss the importance of correct timing of control practices with foliage-chewing insects. With sucking insects. With boring insects. With subterranean insects.

18. Is it a good policy for a grower to have to depend on some agricultural agency to inform him of a pest's appearance and of when control measures should be applied?

19. Why is the Mexican bean beetle a bad pest on bean plantings throughout the summer?

20. Grasshopper plagues are no longer common in the United States. Why?

21. Why is control usually directed against the larvae of moths and butterflies and not against the adults?

22. In what stages are scale insects easiest to control?

23. Why are aphids potentially such destructive pests?

24. Control applications for most sucking pests should be directed to the undersides of foliage. Why?

25. Why are control measures for boring insects usually directed against the adults or the newly hatched larvae?

26. Why is correct timing very important in the control of leaf miners?

27. In what stages are root-feeding insects subject to attack?

28. Plant galls are produced by the irritation of insects. What is the function of the gall?

Chapter 4

THE RELATIONSHIP OF INSECTS TO OTHER ORGANISMS

THE NAMING OF ORGANISMS

The grouping of organisms, referred to as classification, has made scientific progress in biology possible. An organism must be recognized and identified correctly before one can deal effectively with it from the standpoint either of destroying it or of breeding it for useful purposes. Animal and plant classification is based on the Binomial System of Nomenclature in which each organism is known by two Latin names, the genus name and the species name, somewhat similar to our family name and given name. For example, the name of the squash bug is Anasa tristis, Anasa being the genus (to which a number of species may belong) and tristis, being the species to which the squash bug belongs. These two names constitute the scientific name of the insect, which is recognized throughout the world, as opposed to the common name which may differ in each language and locality.

DEFINITION OF A SPECIES. A species may be defined as a "reproductively isolated, naturally distinct group of organisms"; or a group of organisms sufficiently alike to have had the same parents. These definitions are not foolproof, and exceptions to them may be found. Although the species is the working unit of the biologist, genetic modifications within a species frequently occur, especially in the plant kingdom, so that subspecies, variety, race, or strain names are employed in addition to the genus and species names. In scientific writing the scientific name also includes the name of the man that originally described the species.

CLASSIFICATION OF ORGANISMS. Starting with the species as the smallest unit of classification, a number of species that are closely related are grouped together to form a genus; genera (plural of genus) with similar characteristics are combined to form a family; large families are sometimes divided into subfamilies, or families are combined to form superfamilies; similar families are combined to form an order; similar orders to form a class; and similar classes to form a phylum (animals) or a division (plants. The phyla are all combined into the animal kingdom; the plant divisions are combined into the plant kingdom. The two kingdoms include all the living organisms that are or were known to exist on this earth. Different, closely related insects may be classified alike up to the species name and may have the same generic name. As an example we have the native cabbage butterfly, Pieris aleracea, and the imported cabbage butterfly, Pieris rapae. Different species generally cannot interbreed.

TABLE 6

EXAMPLES OF INSECT CLASSIFICATION

	I	II
Kingdom	Animal	Animal
Phylum	Arthropoda	Arthropoda
Class	Hexapoda	Hexapoda
Order	Lepidoptera	Hemiptera
Family	Eucosmidae	Coreidae
Genus	Carpocapsa	Anasa
Species	pomonella	tristis
Scientific name	Carpocapsa pomonella	Anasa tristis
Common name	Codling moth	Squash bug

All insects belong to the class Hexapoda in the phylum Arthropoda. The Hexapoda are divided into twenty-two or more important and several lesser orders, each with many families and genera. The classification and characteristics of the agriculturally important groups of the animal kingdom are shown in Table 7.

THE ORDERS OF INSECTS IMPORTANT AS PLANT PESTS

The class Hexapoda to which all insects belong includes eight horticulturally important groups known as orders. Descriptions of the remaining orders are omitted.

Insect Orders with No Metamorphosis

THE THYSANURA. Silver fish and fire brats.
THE COLLEMBOLA. Springtails.

Insects with a Gradual or Incomplete Metamorphosis

THE EPHEMERIDA. May-flies, shad-flies.

THE ODONATA. Dragon-flies, damsel-flies.

THE PLECOPTERA. Stone-flies.

THE ORTHOPTERA. Adults with chewing mouth parts, usually four wings, the front pair thickened, the hind pair larger and folded fan-like when at rest. Pair of cerci present at end of abdomen. This order consists of roaches which are household pests; mantids which feed on other insects and are beneficial; and grasshoppers, crickets, and walking sticks which are harmful to plants and are important pests of foliage (Fig. 49).

THE ISOPTERA. Termites (Fig. 49).

THE DERMAPTERA. Earwigs (Fig. 49).

THE THYSANOPTERA. Thrips (Fig. 49). Small insects with cone-like mouth parts used in rasping and sucking attached far back on ventral side of head. Four long, narrow wings fringed with long hairs. Tarsi of one or two segments, the tips with bladder-like swellings. Abdomen ten-segmented. Metamorphosis approaching completeness. Some species cause serious injury to plants by attacking stems, leaves, and blossoms; a few are predatory on mites and on small insects.

THE CORRODENTIA. Book lice, psocids.

THE MALLOPHAGA. Biting lice (Fig. 49).

THE ANOPLURA. Sucking lice (Fig. 49).

THE HEMIPTERA. True bugs (Fig. 49). Adults with four wings held flat over abdomen, some species wingless, the front pair of wings, hemelytra, with scutellum between their bases. Piercing-sucking mouth parts attached to front end of head. This group includes many bad plant pests, some animal pests, and some beneficial forms that prey on other insects.

THE HOMOPTERA. Aphids, scale insects, leafhoppers, psyllids (Fig. 49). Piercing-sucking insects with beak arising from back part of ventral side of head nearly between front legs. Wings (sometimes absent) uniform in thickness and held sloping over the body. Many species produce honeydew, a sweet excretion fed on by ants and on which a sooty

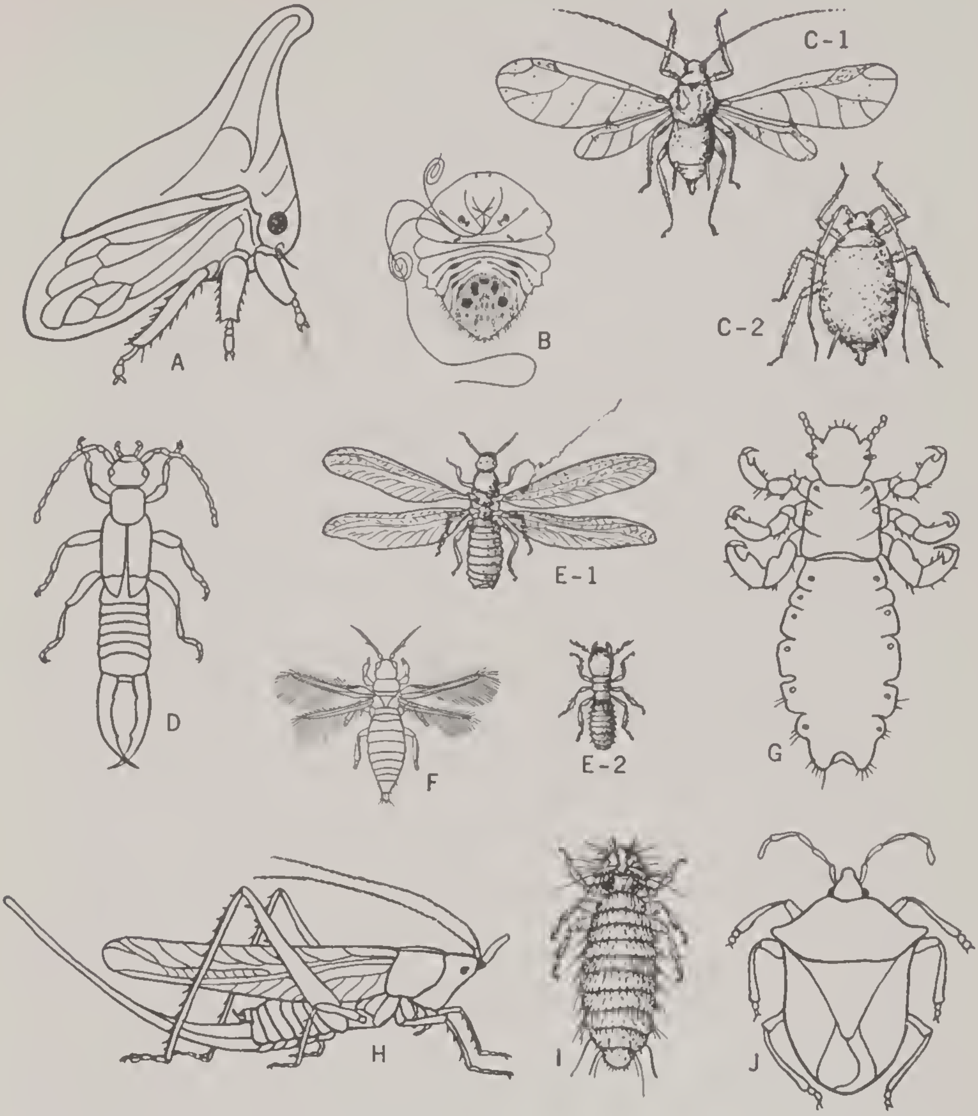


FIG. 49. Insect orders with a gradual metamorphosis. A, membracid leafhopper (Homoptera); B, scale insect (Homoptera); C-1, winged and C-2, wingless aphids (Homoptera); D, earwig (Dermaptera); E-1, winged termite and E-2, worker (Isoptera); F, thrips (Thysanoptera); G, sucking louse (Anoplura); H, locust (Orthoptera); I, chewing louse (Mallophaga); J, bug (Hemiptera) (redrawn from various sources).

mold fungus develops when the honeydew is deposited on foliage and twigs. The lac scale insect is valuable for the production of shellac, which is an alcoholic solution of the wax-like scales covering the bodies.

Insects with a Complete Metamorphosis

THE COLEOPTERA. The beetles, curculios, weevils (Fig. 50). Adults hard-bodied, nearly always with four wings, the front pair, called elytra, thickened and horny, the hind pair membranous. Mouth parts chewing in both larvae and adults. Many destructive plant pests in this group. Some species attack stored grains and foods and some attack structural timber. Some groups, such as the lady beetles and tiger beetles, beneficial, feeding on soft-bodied insects.

THE NEUROPTERA. Dobson flies, fish flies, lacewings, aphid lions, ant lions (Fig. 50).

THE TRICHOPTERA. Caddice flies, caddice worms.

THE LEPIDOPTERA. Moths, butterflies, skippers (Fig.50). Adults with four membranous wings usually covered by overlapping colored scales. Mouth parts, long sucking tube coiled under head. Larvae, called caterpillars, have chewing mouth parts. Many serious plant pests among the larvae of this group. Some are stored-products pests. The silkworm which produces millions of dollars worth of silk annually is a member of this order.

THE MECOPTERA. Scorpion-flies.

THE DIPTERA. Flies (Fig. 50). Adults with only two wings, hindwings replaced by knob-like halteres. Mouth parts either sponging or piercing-sucking. Larvae called maggots. Some bad plant pests in this group, but most are pests of man and animals. May carry diseases. Some forms such as predatory robber flies and parasitic flies are beneficial. Bee flies and syrphid flies of some value as pollinators.

THE SIPHONAPTERA. Fleas (Fig. 50).

THE HYMENOPTERA. Sawflies, bees, wasps, hornets, ants (Fig. 50). Adults usually with four membranous wings with few cross veins. Hindwings smaller. Mouth parts chewing or chewing-lapping. Females usually with an ovipositor or a sting. Larvae chewing or reduced. The members of the sawfly group in their larval stages are all harmful to plants. Some species in other groups also harmful to plants. Bees

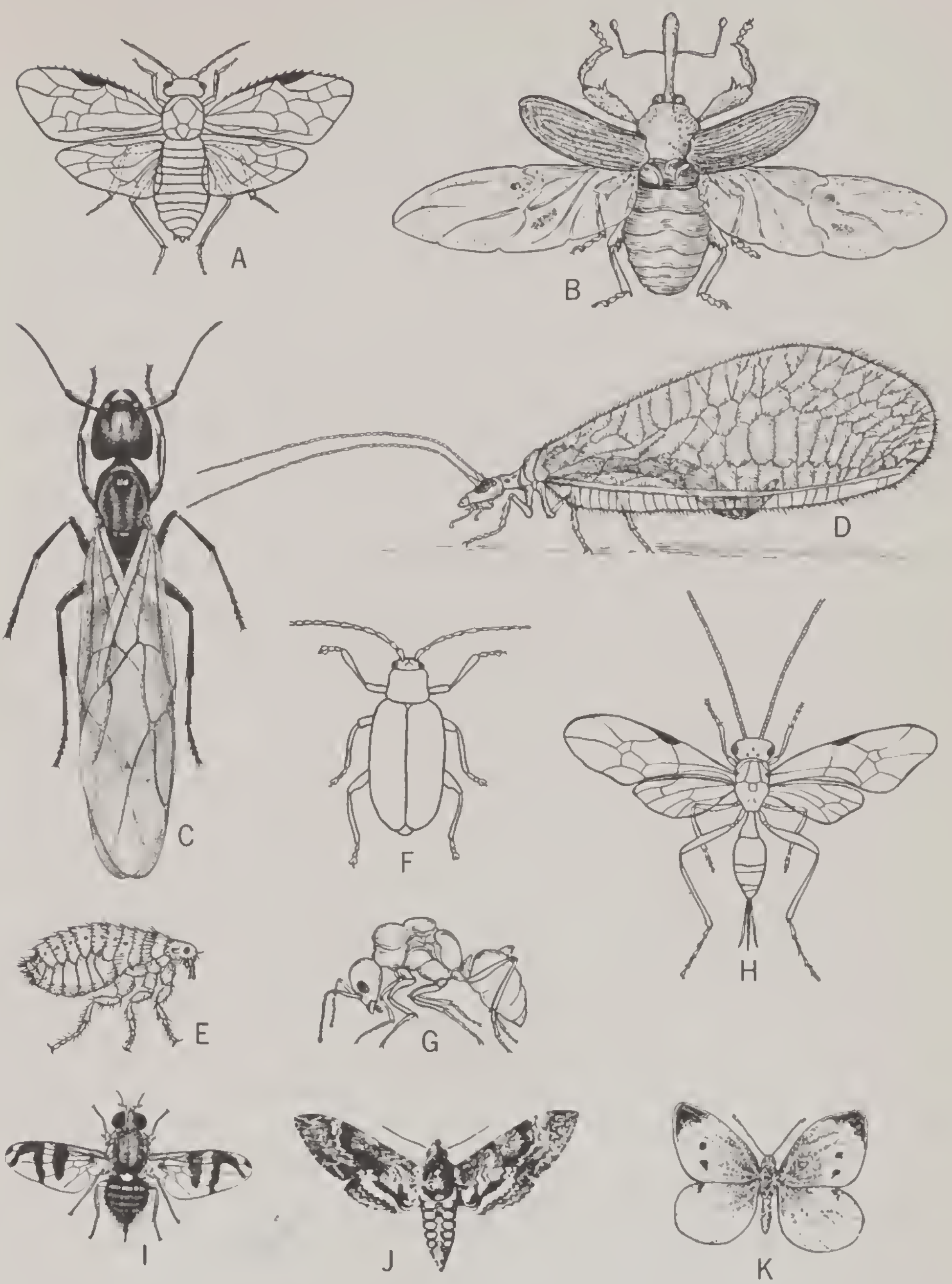


FIG. 50. Insect orders with a complete metamorphosis. A, sawfly (Hymenoptera); B, weevil or curculio (Coleoptera); C, carpenter ant (Hymenoptera); D, lacewing fly (Neuroptera); E, flea (Siphonaptera); F, beetle (Coleoptera); G, Argentine ant (Hymenoptera); H, parasitic wasp (Hymenoptera); I, fruit fly (Diptera); J, hawk moth; K, butterfly (Lepidoptera). (Redrawn from various sources.)

mainly beneficial, of great value as pollinators. Many beneficial parasitic insects in wasp group which are often of great help in reducing numbers of harmful crop pests. Honey bees besides being excellent pollinators produce valuable honey and wax. Some members of this group produce galls on plants.

TABLE 7

CLASSIFICATION OF THE AGRICULTURALLY IMPORTANT GROUPS OF THE ANIMAL KINGDOM

Vertebrates (Animals with a Backbone)

Phylum	Class	Characteristics	Examples
Chordata	Mammalia*	Hairy, four-footed, milk-secreting	Mammals such as man, cow, mice, rabbits
	Aves*	Wings and feathers	Birds such as chickens, ducks, robins, hawks
	Reptilia	Cold-blooded, scaly, air-breathing	Reptiles such as snakes, lizards, turtles
	Amphibia	Cold-blooded, moist, soft-skinned; young aquatic with gills; adults with lungs	Amphibians such as frogs, toads, salamanders
	Pisces	Cold-blooded with scales and fins, aquatic, gill-breathing	Fish such as salmon, bass, trout

*Includes forms injurious to plants.

Table 7 (Continued)

Phylum	Class	Characteristics	Examples
Invertebrates (Animals without a Backbone)			
Arthropoda		Chitinous exoskeleton, jointed appendages, segmented body	
	Hexapoda*	Head, thorax, abdomen, 3 pairs legs, wings	All true insects: bugs, beetles, moths, etc.
	Diplopoda*	Head and abdomen, many-segmented, 2 pairs legs per segment	Millepeds
	Chilopoda	Flattened body, head and abdomen, 1 pair legs per body segment, pair poison fangs on first body segment	Centipedes
	Arachnida*	Fused head and thorax (cephalothorax), 4 pairs walking legs, abdomen distinct, unsegmented, no antennae, only simple eyes; no evident body divisions in mites and ticks	Spiders, mites, ticks, scorpions
	Crustacea*	Hard, limey, chitinous exoskeleton, 2 pairs antennae, cephalothorax usually with biramous appendages	Crayfish, crabs, sowbugs, lobsters

*Includes forms injurious to plants.

Table 7 (Continued)

Phylum	Class	Characteristics	Examples
	Symphyla*	Head and abdomen, 12 pairs legs, (tiny, elongated arthropods)	Symphilids
Mollusca*		Soft-bodied, non-segmented, no jointed appendages; body may be enclosed in calcareous shell	Snails, slugs, clams, oysters
Annelida*		Elongated, segmented worms, no appendages	Earthworms, leeches
Nemathelminthes*		Tiny, elongated, cylindrical, unsegmented worms with tough cuticle; many species microscopic	Nematode worms, hookworms, trichinella
Platyhelminthes		Flattened, usually unsegmented worms, many microscopic	Flatworms, flukes, tapeworms
Protozoa		Single-celled animals, often with cilia	Ameba, paramecia, trypanosomes

*Includes forms injurious to plants.

QUESTIONS FOR DISCUSSION

1. Why is the classification of insects important to people that deal with insect control?
2. What would happen if there were no standard system of classification?
3. Why are not definitions of a species foolproof?
4. How do varieties, races, or strains originate?
5. What is the procedure in naming a new, formerly unclassified insect or other organism?
6. Why is it impossible for a person to be proficient in classifying all types of insects?
7. What are the characteristics common to all insects?
8. Is there any value in being able to identify insects to the correct order?
9. Which orders contain species most harmful to plants? To animals?
10. Give an outstanding characteristic of each order that includes important plant pests.
11. Cite examples of beneficial insects.
12. What are the harmful groups, as far as crops are concerned, in the animal kingdom? Give examples.
13. What features distinguish insects from all other organisms?
14. Why are nematode worms usually considered as disease-producing organisms?
15. Can you advance any theories to explain why protozoa are unimportant as the cause of plant diseases but of great importance in the cause of animal and human diseases?

Chapter 5

INVERTEBRATES OTHER THAN INSECTS HARMFUL TO PLANTS

ARTHROPODS OTHER THAN INSECTS

The Millepeds (Diplopoda)

Some 1000 species of this class have been described, but most of them feed on manure and decaying vegetable matter on or in the soil. Some species (Fig. 51E), however, may attack the stems and underground parts of plants, tunnel into the root vegetables, eat planted seed, and bore into fruits

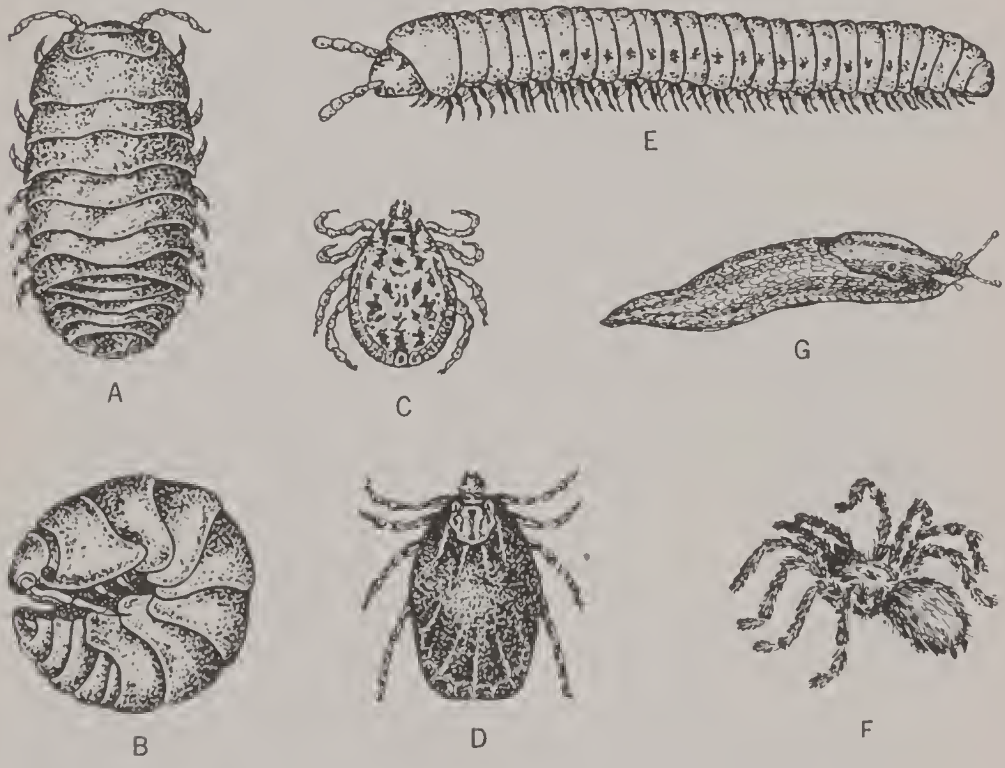


FIG. 51. Some common invertebrates other than insects. A, B, sowbugs or pillbugs (Crustacea); C, D, male and female American dog tick (Arachnida); E, milleped (Diplopoda); F, spider (Arachnida); G, slug (Mollusca). (Redrawn from various sources.)

that are in contact with the ground. Most millepeds have an offensive odor that tends to protect them from their predators. They have chewing mouth parts and no metamorphosis. The young when they hatch from eggs laid in clusters in the soil resemble the full-grown milleped except for size, number of body segments, and legs. Like insects, they breathe through spiracles and undergo a series of molts as they grow. When at rest or disturbed, they generally curl up like a watch spring. They grow very slowly, and in northern regions there is probably only one life cycle a year. Millepeds overwinter in partly to fully grown stages in protected places in the soil or under objects resting on the soil.

The Spiders (Araneida) and the Mites and Ticks (Acarina)

The spiders are beneficial, feeding mainly on insects and on other small organisms. The ticks (Fig. 51C and D) are pests of man and animals, sucking their blood and transmitting diseases. The mites (Fig. 52) include serious pests of both animals and plants. Spiders have a head and thorax fused together to form a cephalothorax from which the four pairs of legs originate and an abdomen that is constricted at the point of attachment to the cephalothorax (Fig. 51F). Mites and ticks are distinguished from spiders in that the abdomen of mites and ticks is joined to the cephalothorax with little or no indication of a division between these two regions, the entire body tending to present a sac-like appearance. Mites and ticks differ mainly in size—the smaller species that are hardly visible to the eye are referred to as mites or red spiders.

GENERAL CHARACTERISTICS OF MITES AND RED SPIDERS. Mites and red spiders are common and destructive pests of many different plant species grown under glass or outdoors. They pierce the plant tissue with their sharp mouth parts, sucking up the sap and destroying the chlorophyll. This injury on foliage may result in a gray or brown mottling of the foliage or in the formation of galls or growths. Many species of mites are predatory or parasitic on insects and may be considered beneficial.

Mites have one or more pairs of simple eyes placed laterally on the forward part of the body. They breathe either by tubular tracheae or directly through the body surface. The spiracles are generally located on the dorsal side near the mouth parts. Most species are oviparous, some are ovoviviparous, and a few are viviparous. Most of the mites that attack plants are divided into two groups: mites or red spiders (Tetranychidae) and gall, rust, or blister mites (Eriophyidae). Since these two groups differ greatly in habits they are considered separately.

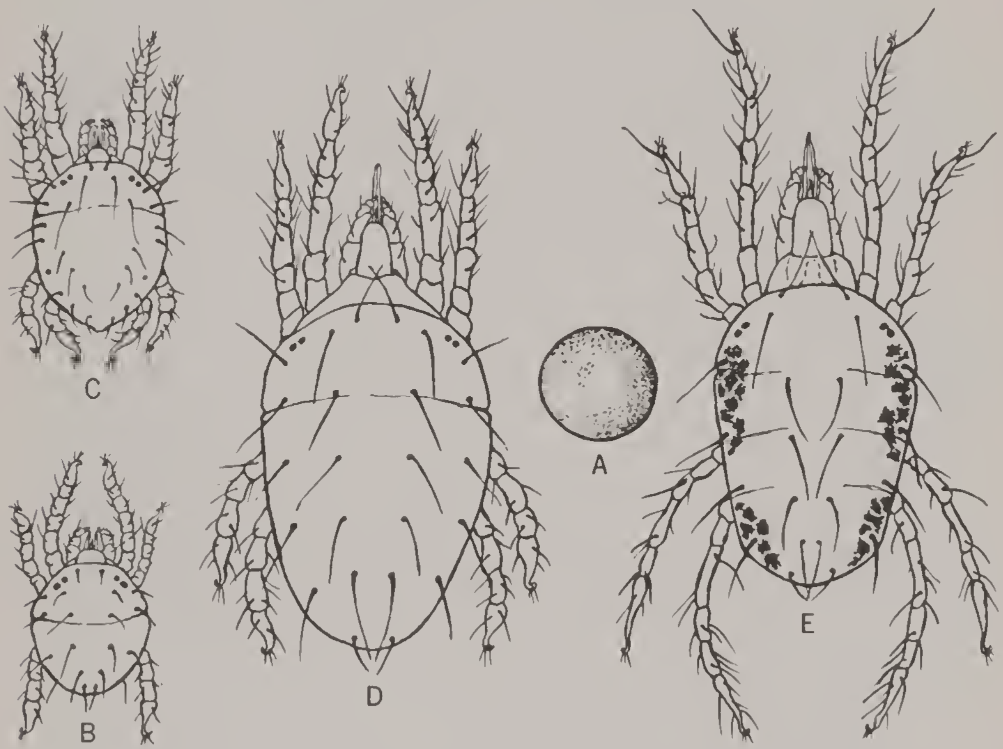


FIG. 52. The developmental stages of the two-spotted mite. A, egg; B, larva; C, protonymph; D, deutonymph; E, adult (redrawn from Peairs, Insect Pests of Farm, Garden, and Orchard).

The Red Spiders or Mites (Tetranychidae). These are actively crawling mites in which the eyes are recognizable as red spots on the front end of the body, the ends of the tarsi have peculiar tenent hairs each with a transverse hook at the tip, and the mouth parts are needle-like and covered at the base by a mandibular plate. The usual mode of respiration is by means of a simple tracheal system with spiracles dorsal above the mandibular plate. Mites commonly cover leaf surfaces with fine webbing.

The life stages of these mites consist of egg, larva (with three pairs of legs instead of four), two nymphal stages (protonymph and deutonymph) that resemble the adult, and the adult (Fig. 52). Each molt is preceded by a quiescent stage of a day or two during which the mites are very resistant to chemical control.

The females lay a few eggs each day for about 2 to 3 weeks. Since the complete life cycle takes from 15 to 20 days under favorable conditions, the broods overlap, and all stages may be found at the same time. There are several generations a year for most species. Some species overwinter in the egg stage on their host plants, whereas others overwinter as adults and nymphs under the bark of trees, under dead leaves, or in the ground. In southern states mites may breed continuously, with their development slowed up considerably during the colder months.

Foliage injured by mites first takes on a grayish, speckled appearance and later turns rusty or brownish (Fig. 53). Plants or their fruits are stunted, and in severe cases defoliation occurs. A continuous, heavy infestation usually results in plants becoming greatly stunted or killed outright. Mites prefer the undersides of foliage but may be found on both sides under conditions of heavy infestation. They flourish during warm, dry weather and are not generally troublesome during cool, wet seasons. The seasonal life histories of two common representative mites, the European red mite and the two-spotted mite, are illustrated in Fig. 54.

The Gall, Rust, and Blister Mites (Eriophyidae). The mites in this group (Fig. 55) are extremely minute, with various species being called gall mites, russet mites, rust mites, or blister mites from the nature of their injury to foliage or fruit. Some mites in this group cause abnormal development of the epidermal plants cells or a deformation of the plant hairs which then appear as brightly colored patches on the foliage and are often mistaken for fungous growth. This type of abnormal growth is termed an erineum.

The mouth parts of the Eriophyidae are similar to those of the Tetranychidae. The mites use these mouth parts in penetrating into leaf tissue to produce galls or blisters; in feeding externally to produce silvery or rusty splotches on foliage or fruit; or in irritating the tissue to produce an erineum. The mites have no external metamorphosis, both

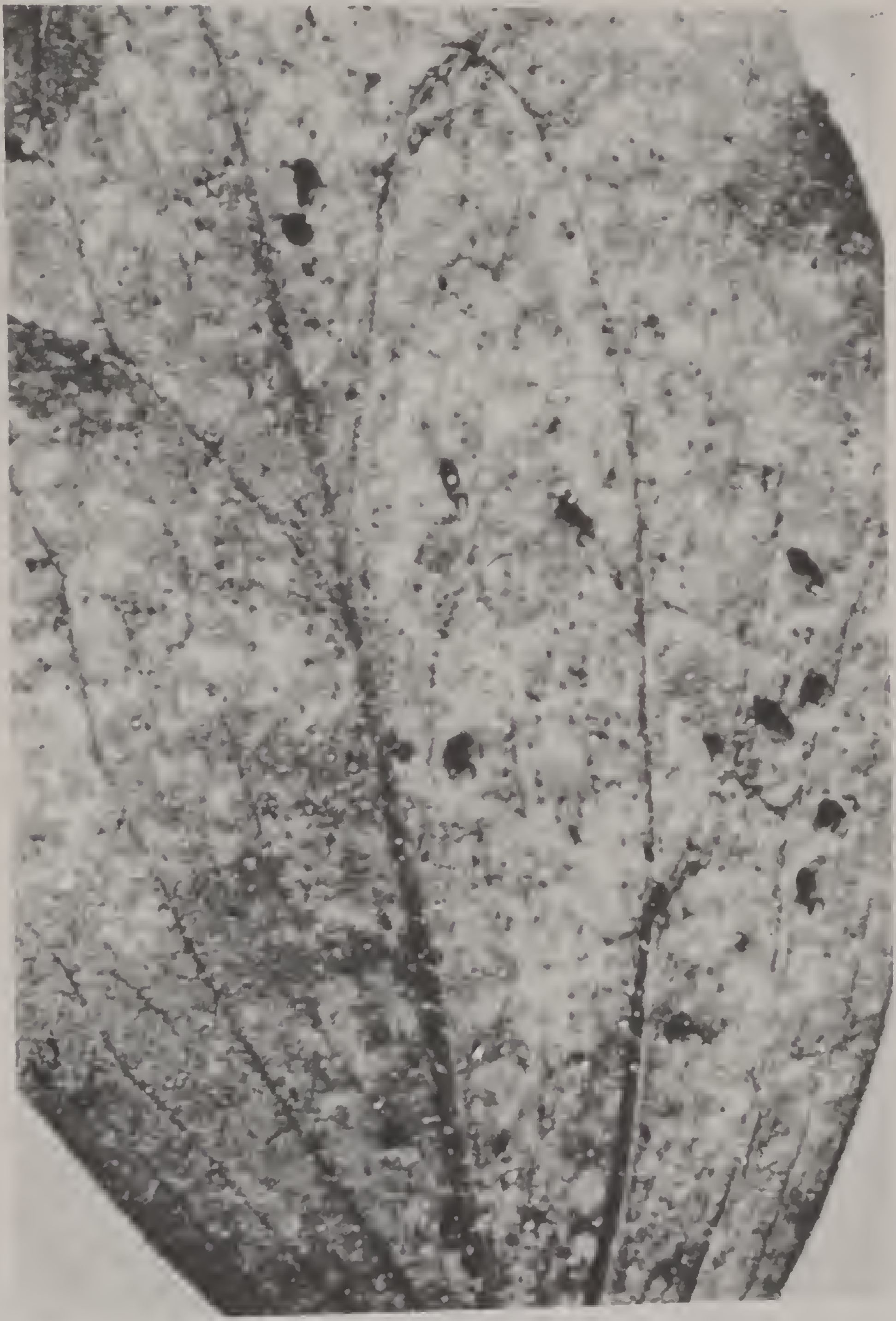


FIG. 53. The two-spotted mite, its eggs, and injury on a sweet pea leaf.

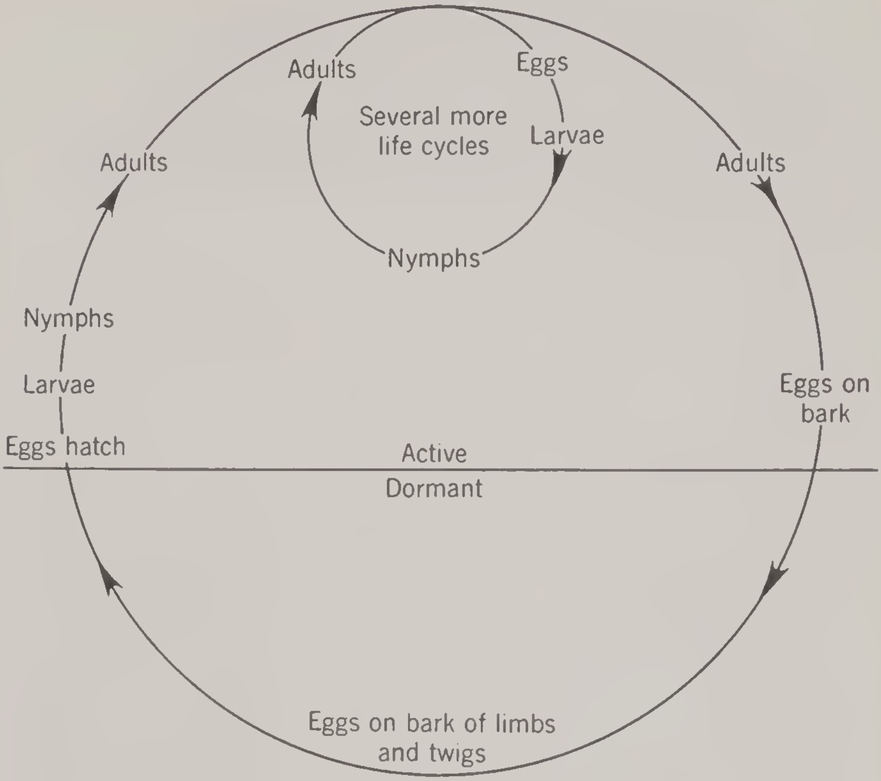


FIG. 54. The life history of the European red mite (Paratetranychus pilosus). The life history of the two-spotted mite (Tetranychus bimaculatus) differs only in that it overwinters in the adult stage under bark, among leaves, or in the soil.

the nymphs and the adults having only two pairs of five-segmented legs with a feathered hair extending from the tip of each tarsus. The life cycle generally consists of the egg, two nymphal stages, and the adult. The tomato russet mite has a rather unusual type of reproduction. The unfertilized females produce males which in turn fertilize the females to produce female progeny. The Eriophyidae are whitish and have a somewhat worm-like appearance with a dorsal thoracic shield and an elongated, ringed abdomen with a pair of caudal setae extending from the end. The life cycle of these mites varies from 1 to 3 weeks under normal conditions.

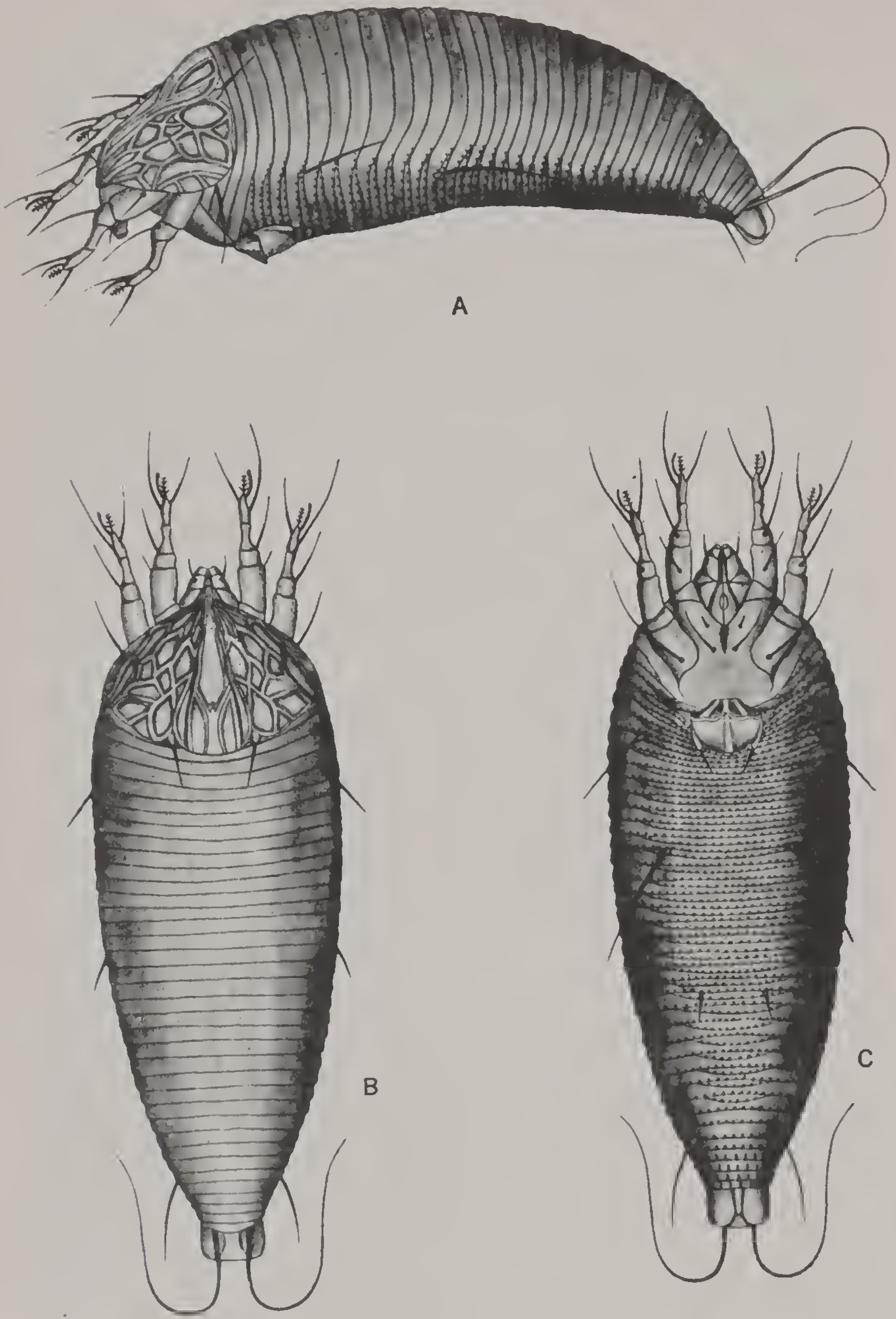


FIG. 55. The maple bladder-gall mite (*Vasates quadripedes*). A, side view; B, dorsal view; C, ventral view (from Hodgkiss, *N. Y. Agr. Expt. Sta. Tech. Bull.* 163).

TABLE 8

SOME IMPORTANT MITES

Tetranychidae

Name	Host Plants
Boxwood mite (*Neotetranychus buxi*)	Boxwood
Citrus red mite (*Paratetranychus citri*)	Citrus
Clover mite (*Byrobia praetiosa*)	Deciduous fruit trees, clover, other forage crops
European red mite (*Paratetranychus pilosus*)	Deciduous fruit and other trees
Pacific mite (*Tetranychus pacificus*)	Fruit trees, milkweed
Six-spotted mite (*Tetranychus sexmaculatus*)	Citrus
Southern red mite (*Paratetranychus ilicis*)	Deciduous plants
Spruce spider mite (*Paratetranychus ununguis*)	Needled evergreens
Two-spotted mite (*Tetranychus bimaculatus*)	Deciduous plants

Eriophyidae

Name	Host Plants
Citrus rust mite (*Phyllocoptruta oleivora*)	Citrus
Maple bladder-gall mite (*Vasates quadripedes*)	Red and sugar maples
Pear leaf blister mite (*Eriophyes pyri*)	Pear and apple
Rust mite (*Phyllocoptes schlechtendali*)	Apple, pear, prune in Northwest
Tomato russet mite (*Vasates destructor*)	Potato, tomato, petunia, nightshade

Table 8 (Continued)

Name	Host Plants
Others	
Bulb mite (*Rhizoglyphus echinopus*)	Bulbs
Cyclamen mite (*Tarsonemus pallidus*)	Cyclamen, begonia, petunia, delphinium, snapdragon, etc.
Mushroom mite (*Tyrophagus lintneri*)	Mushrooms, cheese, grains, flour, cereals

THE SNAILS AND SLUGS (MOLLUSCA)

In the phylum Mollusca, class Gastropoda, the slugs and snails (Fig. 51G) may be harmful to plants, especially in storage cellars, greenhouses, mushroom beds, and vegetable gardens. Snails have hard, calcareous, spiral shells of various forms enclosing their bodies, whereas slugs lack such a protecting shell. A sticky, mucous secretion exudes from the bodies of these gastropods, which leaves a trail along the ground and on the plants where they crawl.

These creatures possess a soft, shield-like covering on the fore part of the back and sides, called a mantle cavity or "lung." Air enters this "lung" through a small hole in the right side of the mantle. The head is well defined and bears a pair of tentacles and a pair of stalked eyes that may be extended or withdrawn. For mouth parts they have a peculiar, tooth-bearing ribbon (called a radula) in the mouth cavity, which is used as a rasping organ in feeding. With these mouth parts they gnaw large, irregular holes in foliage or in plant parts. Unlike insects, the gastropods have a chambered heart and a system of closed vessels with special capillaries extending into the respiratory organ or "lung."

The snails and slugs are hermaphroditic (both sex organs in the same individual) but not self-fertilizing. They are mainly oviparous, with little metamorphosis taking place during their development. Their eggs are deposited in masses under objects in damp places throughout the active season so that all stages of snails and slugs may be found at the same time. It takes at least a year for most species to reach maturity.

Slugs are nocturnal creatures and come out only after dark to feed. In the daytime they may be found in dark, damp places along hedgerows, in soil cracks, and underneath damp refuse. In greenhouses they are commonly found under pots and flats. They pass the winter below the frost line in the ground, in drain pipes, in cellars, in greenhouses, in pits, on well walls, under mulches, and along foundations. They evidently cannot withstand temperatures below freezing. Some species of slugs when full grown may attain a length of nearly a foot, although most species are not more than a few inches long. They tend to be most troublesome in cool, damp seasons or in places kept damp by poor drainage or by irrigation.

Few species of land snails are harmful to cultivated plants. Some species have been observed feeding on citrus foliage and other plants in the tropics and in greenhouses. Thirty-two species of garden slugs have been reported in the United States. The native species are relatively unimportant as crop pests, but occasional outbreaks occur. Three introduced species, the spotted garden slug, *Limax maximus*, the tawny garden slug, *Limax flavus*, and the true garden slug, *Deproceras agrestis*, are the main pests of gardens and greenhouse plants in the seaboard states. The true garden slug is the smallest of the three species and also the most common and most destructive.

THE EARTHWORMS (ANNELIDA)

The earthworms are beneficial to plants because they help break down organic matter, aerate the soil, and mix soil layers. On golf greens they are considered harmful because of their casts (excreta), left on top of the close-cut greens. They should be encouraged in fields and gardens by adding organic matter to the soil in the form of animal manures and composted plant remains.

THE NEMATODE WORMS (NEMATHELMINTHES)

Most forms in this phylum are animal parasites or free-living in the soil. One microscopic group in the class Nematoda, family Tylenchidae, includes important plant parasites.

These are commonly called roundworms, ellworms, nemas, or nematode worms. They may attack any part of the plant, but most species limit their attack to the roots or underground parts.

Characteristics. Structurally, the nematodes are very simple, tiny, unsegmented worms with a tough, transparent cuticle and an inner muscular layer that makes movements possible (Fig. 56). The head end is blunt, with a centrally located mouth, whereas the posterior end is generally pointed. The nematodes feed on juices that they make available from living cells by boring into them with a barbed, hollow, spear-like stylet attached to the pharynx. The oesophagus is a suctorial tube with two oesophageal bulbs. The intestine is usually a straight tube with an opening near the posterior end. They have no definite circulatory system, and organs of respiration are lacking. Their nervous and excretory systems are simple.

The sexes are usually separate, and the females are oviparous, but a few species bear living young. Hatching may occur without fertilization. There is no definite metamorphosis, but molts occur, and the females in some species when mature become swollen and pear-shaped, their bodies distended by eggs.

Activities. Some species invade the food-containing tissues of plants and stimulate cell growth, which results in enlargement and distortion of invaded tissues (Fig. 57). Others may cause yellowing, browning, and death of tissues. Most species have a cyst or a dormant larval stage that is strikingly adapted to withstand conditions unfavorable for the continuation of the species. In some nemas such as the golden nematode the body cuticule of the female forms a tough, round cyst around the eggs, which may keep the eggs alive for several years. Hatching may finally occur under the proper environmental conditions. This egg-cyst stage is the overwintering stage for many northern species of nematodes. To complicate control further and to insure continuance of the species, the eggs and larvae from a cyst do not all become active at the same time but hatch and emigrate over a period of years. Dormant larvae in nematode galls on wheat (T. tritici) may remain dormant for many years and may resume their life cycle when favorable moisture conditions arise. A case in wheat galls where activity was resumed after a dormancy of

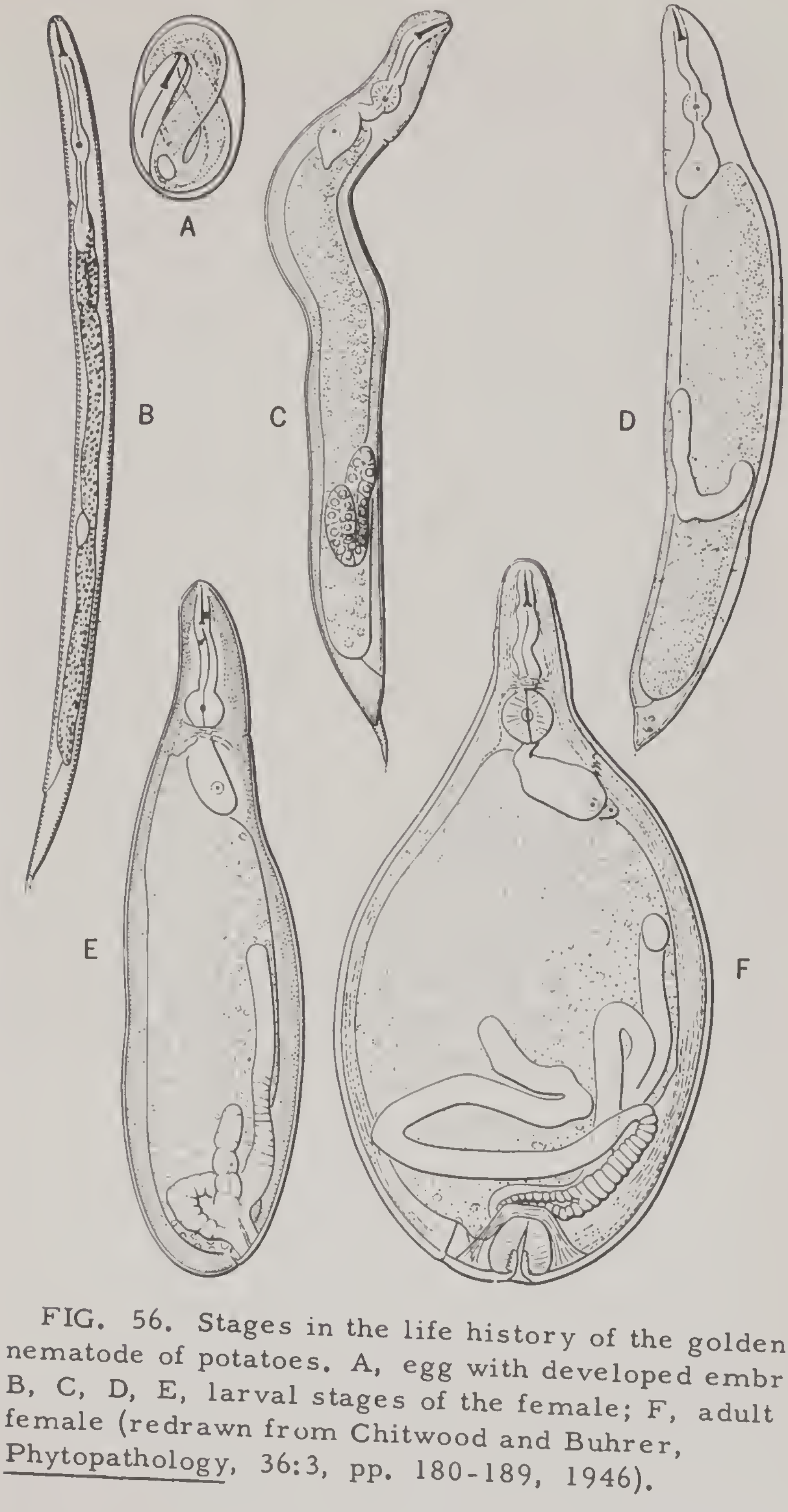


FIG. 56. Stages in the life history of the golden nematode of potatoes. A, egg with developed embryo; B, C, D, E, larval stages of the female; F, adult female (redrawn from Chitwood and Buhrer, Phytopathology, 36:3, pp. 180-189, 1946).

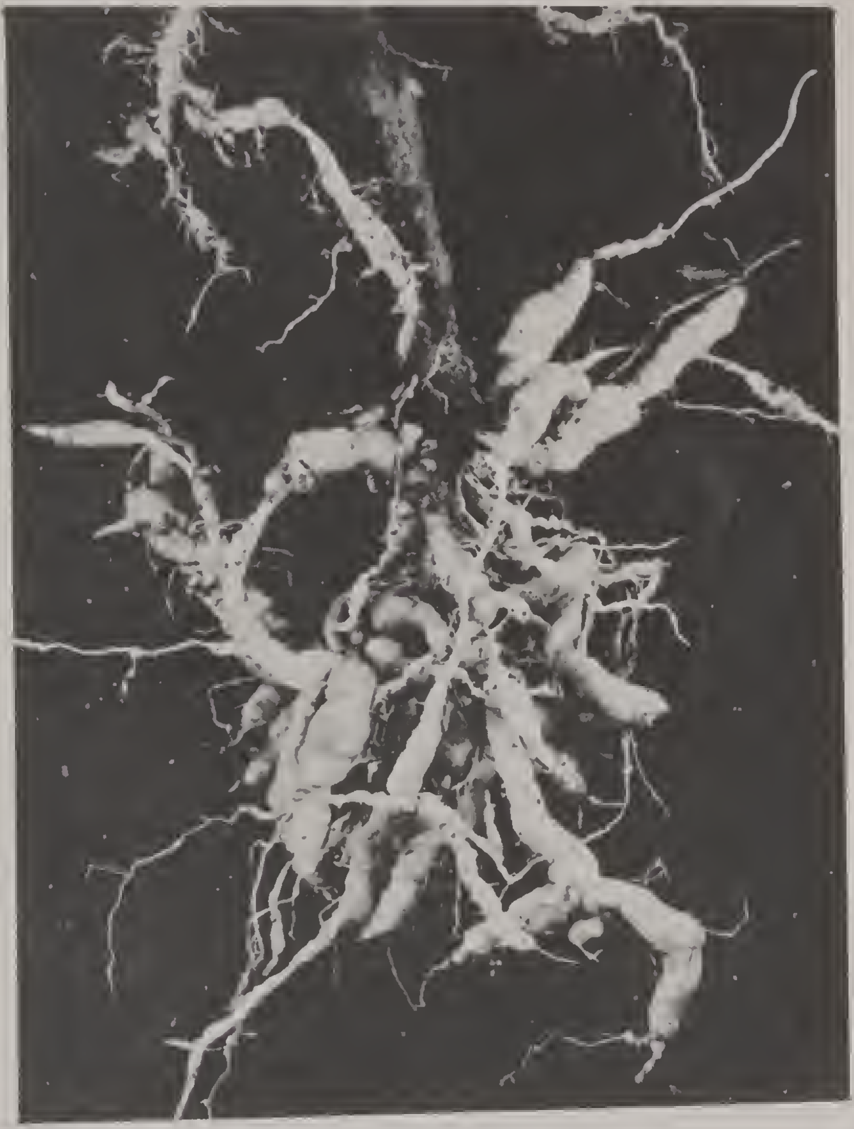


FIG. 57. Root knot nematode injury to tomato roots.

27 years has been recorded. Some nematodes such as the root knot nematode cannot successfully overwinter in the colder northern states and therefore tend to be a pest there only in greenhouses. Some parasitic nematodes may live freely in the soil for months without the presence of host plants. The life cycle of nematodes takes from 2 weeks to 2 months, depending on the species and on the weather. Nematodes may be transferred from place to place with infected plants or plant parts, by irrigation water, by wind, by ani-

mals, and by farm implements. The life cycle of the root knot nematode is given in Fig. 58.

The phylum Platyhelminthes and the phylum Protozoa contain many animal parasites, but no species in these phyla is known to attack plants.

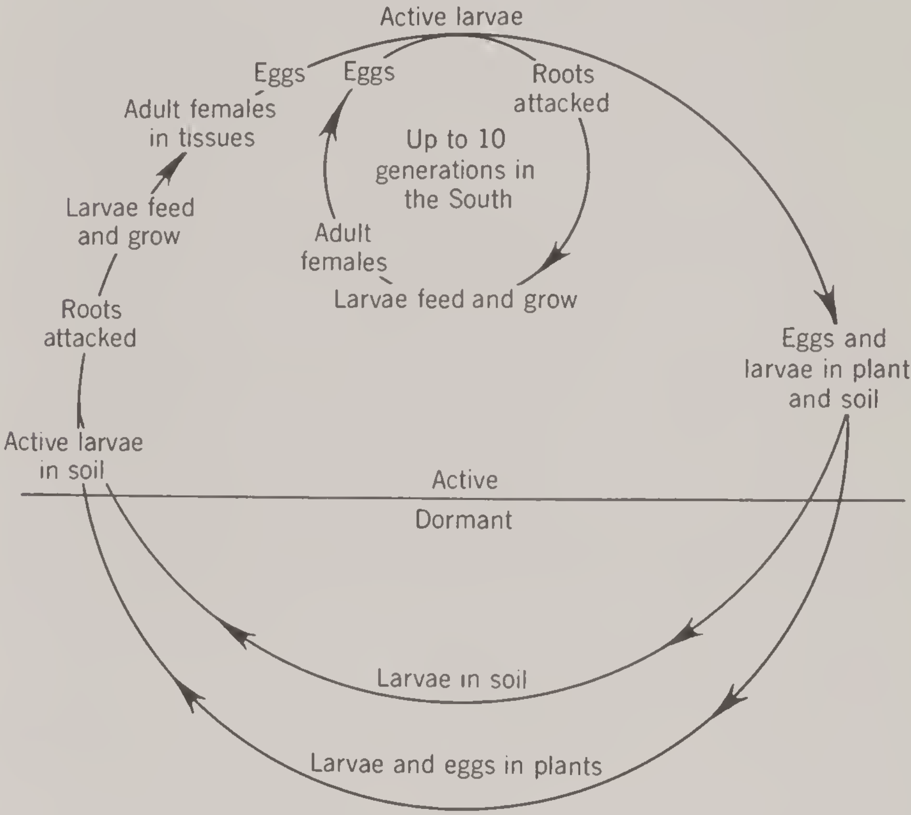


FIG. 58. The life history of the root knot nematode (Heterodera marioni).

TABLE 9

SOME IMPORTANT PLANT NEMATODES

Name	Host Plants
Wheat nematode (*Tylenchus tritici*)	Wheat, rye above ground
Stem and bulb nematode (*T. dipsaci*)	More than 100 species of plants, bulbs; known as "ring disease"
Burrowing nematode (*T. similis*)	Banana, sugar cane, sweet potato, edible canna
Root nematode (*T. pratensis*)	Cotton, potato, violet, lily of the valley, etc.
Citrus nematode (*T. semipenetrans*)	Citrus
Sugar beet nematode (*Heterodera schachtii*)	Beets, crucifers
Root knot nematode (*H. marioni*)	More than 1000 different hosts
Strawberry nematode (*Aphelenchus fragariae*)	Strawberries
Fern nematode (*A. olesistus*)	Leaves of ferns, begonia, gloxinia
Chrysanthemum nematode (*A. ritzema-bosi*)	Leaves of chrysanthemums
Coconut-palm nematode (*A. cocophilus*)	Coconut palms; known as "red ring disease"
Meadow nematode (*Pratylenchus scribneri*)	Potato, boxwood, etc.
Potato rot nematode (*Ditylenchus destructor*)	Potato
Golden nematode (*Heterodera rostochiensis*)	Potato

QUESTIONS FOR DISCUSSION

1. How do millepeds differ from insects?
2. Why are mites important plant pests?
3. From the structure and habits of mites would you think that they are easier or harder to control than insects?
4. How do the Tetranychidae differ from the Eriophyidae? Which should be easier to control?
5. Since mites are wingless, how are they able to disseminate themselves so well?
6. How do slugs differ from the other pests considered so far?
7. What conditions favor the development of slugs?
8. In what respects are earthworms beneficial?
9. What characteristics make nematodes hard to eradicate?
10. How are nematodes spread from place to place?
11. In what ways do plants react to the presence of nematodes?
12. How should one go about checking on the presence of nematodes in a plant? In the soil?

Chapter 6

CONTROL OF INSECTS AND OTHER INVERTEBRATES

Harmful organisms may be held in check by many factors—those that occur naturally and are uncontrolled by man may be classified as natural controls; those that man initiates and regulates may be classified as applied controls. Natural controls are of primary importance in keeping the numbers of pests at low levels; but when these fail, as they frequently do, plagues arise, and growers must apply control measures of their own or else suffer great crop losses.

NATURAL CONTROLS

Natural controls are Nature's own methods of keeping populations within bounds. They consist of physical factors such as adverse weather, climate, and physical environment and of biological factors such as predators, parasites, diseases, and food supply.

Weather and climate are probably the most important factors that directly or indirectly limit the abundance of insects. A knowledge of what is beneficial and of what is harmful to certain insect species often makes it possible to predict their outbreaks. The effects of weather and climate on insects has been discussed previously and will not be covered again here. Years ago geographical features such as oceans, rivers, mountain ranges, and deserts were physical barriers to the spread of insects, but increased travel and speed of travel has decreased the importance of such barriers. Many pests may now successfully hitch-hike from continent to continent, and there is always danger that they will become established if conditions are favorable.

All the organisms that are naturally present in an environment and that attack and destroy insects or compete with them for food comprise the biological factors of control. These biological factors are of considerable importance, and sometimes they exert a greater influence than the climatic factors in reducing the abundance of pests. Probably every species of insect has parasites, predators, and diseases that attack it during some stage or stages in its existence, and these at times are so helpful to growers that other control measures are unnecessary.

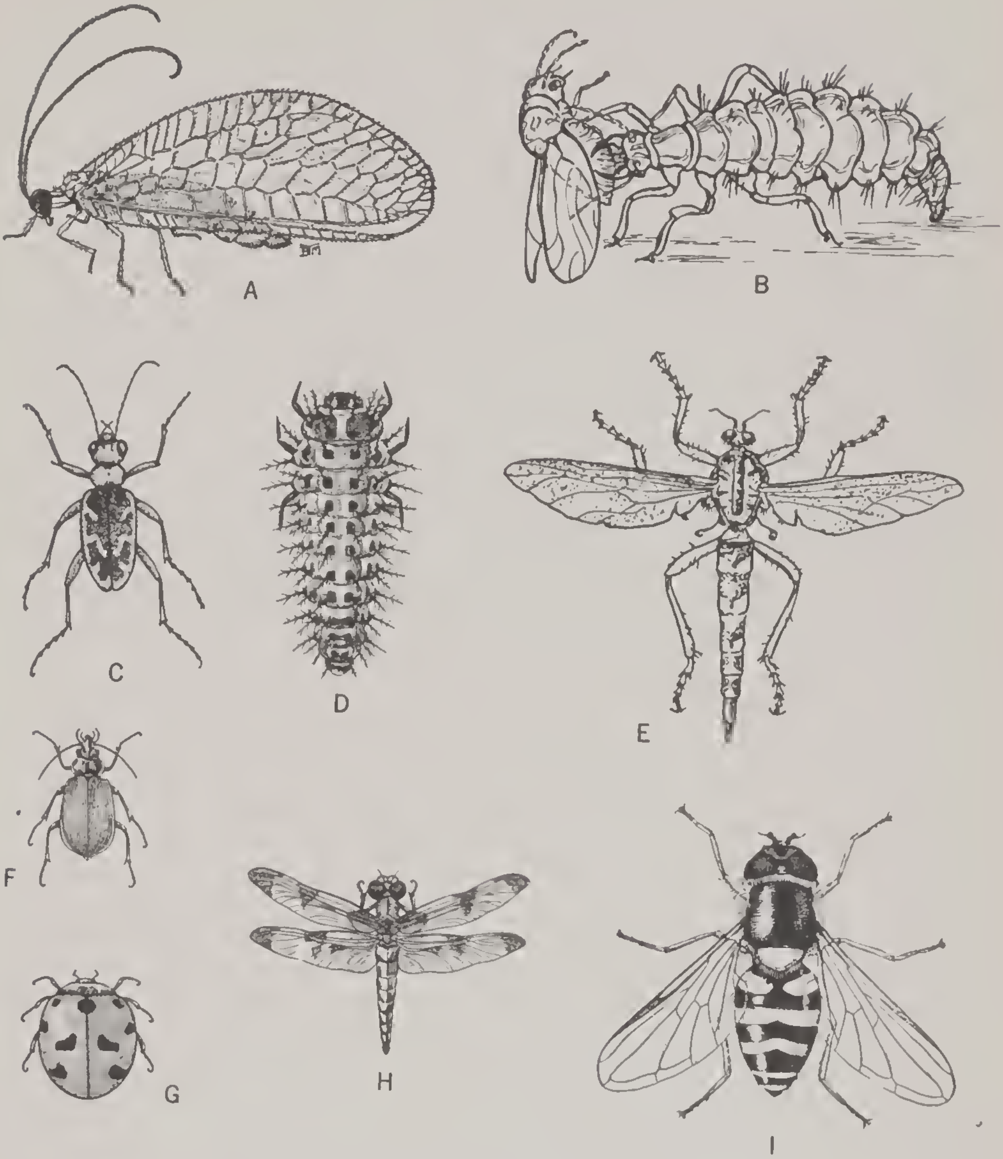


FIG. 59. Predatory insects. A, lacewing fly; C, tiger beetle; D, larva of lady beetle; E, robber fly; F, ground beetle; G, lady beetle; H, dragon fly; I, syrphid fly (larva a predator). (Redrawn from several sources.)

PREDATORS. Predators are organisms that attack, kill, and eat other organisms but otherwise do not stay in contact with them. The most important predators of insects are other insects and closely related arthropods (Fig. 59). These consist mainly of numerous species of lady beetles and their larvae, which feed mostly on aphids and scale insects; lacewing flies and their larvae, known as aphid lions; syrphid fly larvae; nocturnal ground beetles and their larvae; tiger beetles; the praying mantis; robber flies; predaceous bugs; and spiders. Heavy aphid infestations are frequently completely destroyed by lady beetles, syrphid fly larvae, and aphid lions, when sufficient time is allowed. At times some insects will eat each other when competing for the food of a plant. Usually only one corn earworm is found in an ear of corn although many eggs are laid on the silks, because the survivor destroyed all the others that got in its way.

A majority of the land birds are insectivorous or partly so and are of great value in destroying insects. Some heavy insect infestations have been eliminated by birds alone. A fuller discussion of birds and their value is given in Chapter 11. Also, many small vertebrate animals are partly or wholly insectivorous and help in insect control. Among these are moles, shrews, skunks, bats, snakes, newts, lizards, toads, and fresh-water fish.

PARASITES. Parasites are organisms that live on or in the bodies of other organisms and feed on them, either greatly weakening or finally killing the host—usually when the parasite's development is complete. The most important parasites of insects are other insects. These insect parasites in their adult stage are generally minute to large wasp-like insects and flies whose larvae feed within the eggs or bodies of many destructive insects. In some fields hardly a tomato hornworm escapes a tiny, braconid wasp. The hornworm shows no signs of the presence of these parasites until they emerge from its body and build conspicuous white cocoons over it (Fig. 60). The caterpillar then sickens and dies. The tiny egg parasite (Trichogramma minutum) is considered to be of great value because it attacks many different insect hosts, whereas most insect parasites limit their attacks to one insect species or closely related ones.

DISEASES. Both fungous and bacterial diseases are common among insects and take heavy tolls. The fungus Beauveria globulifera under favorable weather conditions reduces chinch bug numbers so greatly that other control measures are unnecessary. Several species of fungi under damp hot conditions in Florida attack scale insects on citrus and effectively reduce their numbers. Many other fungous diseases of insects have been noted and under the proper conditions these diseases greatly reduce the numbers of a species that they attack. Bacterial diseases are also prevalent in insects, especially the larvae, and also help in natural insect control.

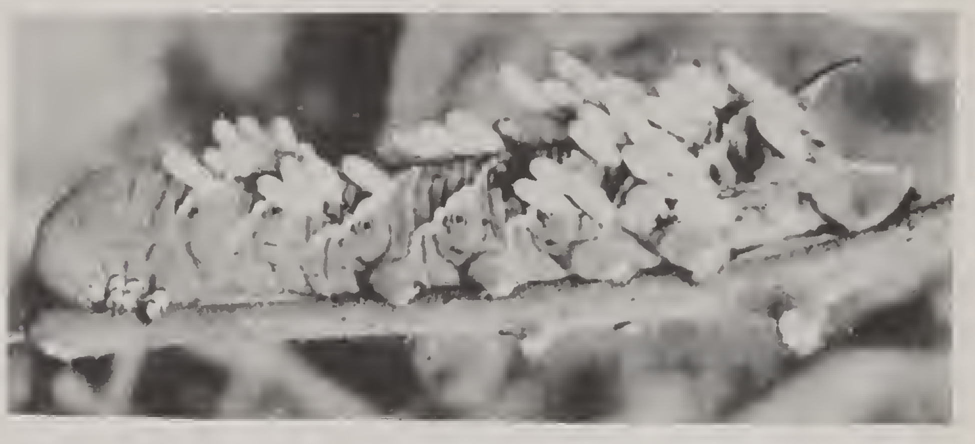


FIG. 60. Cocoons of a hymenopterous parasite attached to the body of a tomato hornworm which is slowly dying.

APPLIED CONTROL MEASURES

Applied control measures are those initiated by man and dependent on him for their success. They may be divided into (1) mechanical methods and devices; (2) cultural practices; (3) applied biological control; (4) use of resistant or immune plant varieties; (5) legal control; and (6) chemical control. Chemical control is discussed in Chapters 7-10.

MECHANICAL METHODS AND DEVICES. These consist of methods or devices that kill or capture insects directly or exclude them without the use of insecticides.

1. Screens or netting to protect plants. This is practical only on a small scale where individual plants or valuable crops must be protected from insects that attack above ground.

2. Light traps, bait traps, and electric traps. Light traps are used for night-flying insects, but they generally catch as many beneficial as harmful species. Bait traps have been successful for some insects such as Japanese beetles (Fig. 61), flies, codling moth, oriental fruit moth, and apple maggot

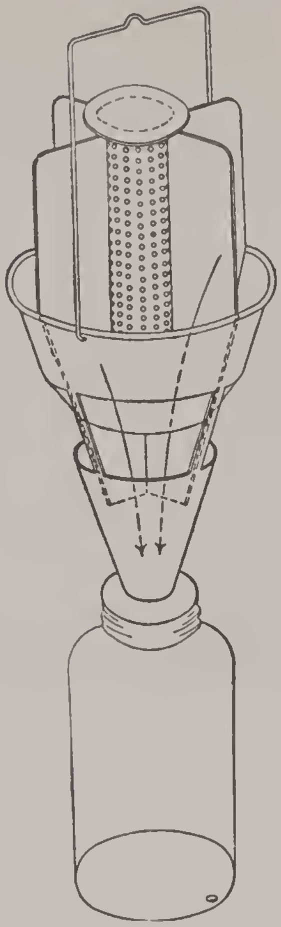


FIG. 61. A Japanese beetle trap, effective only if many are used over a wide area (from Rex, N. J. Dept. Agr. Circ. 242).

flies, but, in general, practical control is not possible by this method alone. Bait traps for some of these pests are useful to check on their appearance and abundance in relation to the timing of control measures. Electric traps that electrocute insects may have either a light (at night) or a bait as an attractant, or they may be installed like a window screen. They are most valuable for fly control in buildings.

3. Hand picking of insects. This is sometimes feasible where only a few plants are involved or where labor is cheap. Other hand methods are digging out and killing borers with a knife or a wire; and jarring trees and collecting the insects on a sheet spread underneath—this method is useful for insects that drop when disturbed, such as plum and quince curculios.

4. Erection of barriers. Banding of trees with sticky substances is a control method for insects that cannot fly but must crawl up the trees to lay eggs or feed. Tanglefoot bands are generally used for insects such as cankerworms and ants. Linear barriers such as deep, dusty furrows or metal strips are sometimes used to prevent invasion of a crop by migrating insects such as chinch bugs, armyworms, or Mormon crickets. Banding apple trees with corrugated paper or burlap is a method for capturing overwintering codling moth larvae that hibernate under and in these bands.

5. Flooding and draining. On land where irrigation is practiced or in cranberry bogs, flooding at the right time is often useful in killing insect pests, especially those that are in the soil. The draining of marshes and swamps and the elimination of all standing water not containing fish is one of the best methods of doing away with mosquitoes and some horseflies.

6. Extreme temperatures. Plant products stored below 40° F. are safe from insect attack, since insects are inactive below this temperature. Most insects cannot stand a 125° to 130° F. temperature range for more than a few hours. Such temperatures are often maintained for insect control in granaries, mills, and elevators. For effective kills, enough time should always be allowed for the heat to penetrate. Insects placed in a high-frequency electrostatic field are quickly killed by internal heat generation. This knowledge is utilized in destroying insects without affecting grains and food products (provided the moisture content is low) by passing the materials on a revolving belt through such a field.

7. Removal of all rough and loose bark from the crotches, trunks, and branches of fruit trees. This may be done during the winter or early spring with a jet spray to destroy overwintering codling moth larvae and to remove favorable hibernating places for future generations.

CULTURAL PRACTICES FOR THE CONTROL OF INSECTS. This includes all farm practices to destroy insects or prevent damage by them other than the use of insecticides. Cultural control methods are basic to all other control methods and should never be neglected in favor of chemical control alone. It has been often shown that healthy, vigorous, growing plants are their own best protection from insect and disease damage, and everything should be done to make them so through proper soil preparation and fertilization.

1. Crop rotations. Very few insects are general feeders, and most feed only on one crop or closely related crops. If the crop family grown on the same ground is changed from year to year, insects as well as plant diseases will tend to be starved out, and no build-up of populations will result; this often happens when the same crop is grown in the same fields for many seasons. Much of the increased yield obtained from crop rotations is due to the reduction of insect and disease damage.

2. Sanitation. Sanitation includes the destruction of crop residues by plowing them under, burning them, or feeding them to domestic animals such as hogs, sheep, and poultry; the destruction of weeds and volunteer plants; the elimination of trash piles, weedy fencerows, and bushy hedges that offer hibernating places; and the proper pruning of trees and thinning of fruits. Sanitation is recognized as being of great importance in pest control and is of special importance with insects such as the European corn borer and chinch bugs that hibernate in crop residues or in heavy grass growth. Wormy fruit left lying on the ground under the trees encourages insects such as the codling moth, plum curculio, apple maggot, and the Oriental fruit moth.

3. Timing of Plowing and Planting. Plowing or cultivating at the right time or at proper intervals so as to bury or expose insects can be used to advantage on insects such as white grubs, the corn root aphid, certain grasshopper eggs, the European corn borer, and the Hessian fly. Fall plowing to expose white grubs before they go below the frost line or to bury corn and weed stuble containing corn borers effectively reduces their numbers. The Hessian fly may be controlled by plowing under wheat stubble as soon after harvest as possible. A knowledge of the life history and habits of insects is necessary in order to time such practices to obtain the best results.

Some insects will not deposit eggs on bare ground, and if the fields can be kept barren during their egg-laying periods control will be achieved. The southern corn rootworm, the Japanese beetle, and the Great Basin wireworm are examples of such insects. Other insects such as the pale western cutworm and the seed-corn maggot prefer bare ground for egg laying, and for combating these species bare ground should be avoided during this period.

Time of planting can often be used to advantage in avoiding some insect pests. The corn earworm usually does not attack early planted sweet corn in the northern states. The southern corn rootworm is usually bad on early planted corn. The European corn borer generally infests early and late-planted corn badly (in the two-generation area), but corn planted so that it is 6 inches or less in height during the first egg-laying period usually escapes infestation. Sweet corn in some areas may be planted so as to escape the corn borer and still ripen before the corn earworm moths arrive. The seedcorn maggot is usually less destructive on soil that has not been freshly manured and that has been allowed to dry out for a week or two before planting. Conditions leading to the quick germination of seeds, such as warm weather and shallow planting, also help reduce injury.

The Hessian fly offers an excellent example of insect control by correct timing of wheat seeding. In some years a difference of a few days in the time of winter wheat seeding may mean a good crop or a badly infested one. Sowing should be delayed in the fall so that the most of the flies will have emerged, laid their eggs, and died before the wheat comes up. Normal safe planting dates are obtainable from local agricultural agencies.

INSECT-RESISTANT OR IMMUNE VARIETIES. A resistant plant variety is one that is badly attacked by an insect species only under conditions very favorable to the insect, whereas an immune plant variety is left alone by the insect species under all conditions. Although great advances have been made in recent years in developing disease-resistant or immune varieties of plants, little has been accomplished in developing or selecting plant strains resistant to insect attack. The American grape is resistant to the grape phylloxera (an aphid), but the European grape is very susceptible. By grafting European grapes on American rootstocks, damage from this pest is avoided, and European grapes can be grown. The winged euonymus is immune to the euonymus scale, but all other species of euonymus are highly susceptible. Creeping bent grasses are very susceptible to hairy chinch bug damage, whereas the fescues are relatively resistant. Corn varieties show differences in susceptibility to corn borer attack, and many grain varieties react differently to certain pests.

APPLIED BIOLOGICAL CONTROL. Natural biological control is often aided by encouraging the predators and parasites present in a region or by bringing in and liberating new species from other regions. For imported pests these new parasites and predators are sought in the original home of the pests, reared under artificial conditions, and released in the fields to become established. Sometimes it is practical to rear parasites or predators in large numbers every year for release. This is often done with the parasite of the Oriental fruit moth, *Macrocentrus ancylivora*, and with the tiny egg parasite, *Trichogramma minutum*, that attacks many different insect hosts.

In a few cases disease organisms that attack certain species of insects have been utilized to create epidemics among them. The bacterial organism producing milky disease in Japanese beetle grubs is cultured in the bodies of live grubs and made into a powder for distribution in areas where it does not occur naturally. This disease is supposed to gradually reduce grub populations within a period of several years to the point where they are no longer a problem in treated areas. Many fungous diseases attack insects, but their artificial culture and distribution has not proven practical, since they occur naturally anyway under the proper environmental conditions and are not effective unless these conditions occur.

LEGAL CONTROL MEASURES. Control measures by means of legislation consists mainly in the establishment of quarantines. These quarantines may prohibit the entrance of certain plants or plant products into the country; may allow for inspection and entrance of plant products only when they are found to be pest free or only when disinfested by recognized methods; and may prohibit the movement of plants or plant products from infested to uninfested areas within a country. Thus we may have Federal or international quarantines, interstate quarantines, and local quarantines. Quarantines are not justified when their probable value is less than the cost of maintenance.

Other legal control measures consist of laws regulating the labeling and sale of insecticides to protect growers against frauds (see section in Chapter 7 entitled "Information Given on Commercial Insecticide Containers") and the authorization and support of extermination campaigns against pests.

QUESTIONS FOR DISCUSSION

1. Which are affected more by weather conditions: warm-blooded or cold-blooded organisms?
2. Under present conditions, are foreign pests more or less likely to be introduced into this country than formerly?
3. Why can't we depend on predators and parasites to control harmful insects?
4. Does it do any good to liberate parasites or predators in an area where they are already present?
5. Why aren't fungous and bacterial diseases used more in insect control?
6. Under what conditions would hand picking of pests be feasible?
7. Why isn't control of Japanese beetles practical with bait traps?
8. Why is crop rotation an excellent method of pest control?
9. Name the factors that may encourage the abundance of pests in an orchard or a field?
10. Is timing of planting dates so as to avoid insect pests feasible on field crops? On market garden crops?
11. Can you give any reasons why the breeding of insect-resistant varieties of plants has fallen far behind the development of disease-resistant plant varieties?
12. Why does an introduced pest tend to go on a rampage, providing climatic conditions are favorable?
13. Are quarantines always used for the purpose for which they were created?
14. Some states have a law requiring corn stubble to be plowed under by a certain date in the spring. Is such a law effective in reducing the damage by the corn borer?

Chapter 7

THE CHEMICAL CONTROL OF INSECTS THE STOMACH POISONS

Chemicals that are used in the control of insects are generally referred to as insecticides. Any given insecticide may act in one or more ways, but it is usually grouped according to its chief mode of action. The types are as follows: (1) a stomach insecticide is one that after being swallowed attacks the internal organs; (2) a contact insecticide kills upon contact with some external portion of the body; (3) a residual contact insecticide remains toxic to insects for long periods after application; (4) a fumigant has a great enough vapor pressure, naturally or heat induced, to produce lethal concentrations of vapor in the air; and (5) a repellent is a chemical distasteful or malodorous enough to keep insects away.

HOW INSECTICIDES ARE USED

The correct insecticide and method are determined by the crop and by the nature of the insect pest to be controlled.

1. Insecticides may be applied to the external parts of a plant as sprays or dusts to be eaten by or to make contact with insects.
2. Insecticides may be applied in the soil (soil insecticides) as liquids, powders, or suspensions to kill subterranean pests.
3. Insecticides may be exposed in or expelled into confined spaces so that their vapors or particles will remain in sufficient concentration for a long enough time to kill the insects involved. When a liquified gas such as "Freon," methyl chloride, or superheated oil is used to dispense the insecticide mixed with it in the form of a fog or mist, it is termed an aerosol. Aerosols are colloidal suspensions of solids or liquids in air. They may be effective as stomach insecticides, contact insecticides, or fumigants. They sometimes act very much like fumigants, but the actual method of killing is determined by the insecticide used, the length of time it stays suspended in the air, and the amount deposited on the plants. All the new organic insecticides and most plant-derived ones that can be dissolved in organic solvents may be applied in aerosol form.

4. Insecticides in the form of poison baits may be mixed and applied with food attractive to certain insects.

5. A relatively new method of application termed chemotherapy has been employed with limited success for certain plant-feeding pests. This method makes use of the fact that some plants may absorb through their roots or foliage small amounts of chemicals poisonous to insects but relatively harmless to themselves. These plants then have the power to destroy or repel for some time many of the pests that feed on their juices. Chemicals useful in chemotherapy are referred to as systemic insecticides.

INFORMATION GIVEN ON COMMERCIAL INSECTICIDE CONTAINERS

The information on commercial containers of insecticides is of great importance to the user and should be read carefully before the material is applied. Only too frequently damage to crops or poisoning of man and animals occurs because of vital information overlooked on the label of a package or through carelessness in using the material.

The Federal Insecticide, Fungicide, and Herbicide Act of 1947 specifies the following definite requirements in the labeling of commercial packages of insecticides, fungicides, weed killers, and rodenticides, all grouped together as economic poisons:

1. Information should be neither false nor misleading; and the chemicals shall not be injurious to man, animals, or plants if used as directed or in accordance with commonly recognized practice. The material must come up to the professed standard or quality expressed in its labeling.
2. The name and address of the manufacturer or seller must appear on each package.
3. The name, brand, or trade mark under which the material is sold must be given. The name of an insecticide may be the chemical name, the name based on its chemical formula; the common name, the name used by the general public to designate the material; or the trade or proprietary name, the name given to a product by a company to distinguish it from similar products put out by other companies. The chemical or common names are most useful to the purchasers. The trade names, unless they become common names

through usage, such as Flit and Black Leaf 40, tend to confuse because they do not convey any important information about the material and are legion in number and variety.

4. An ingredient statement or analysis giving the name and percentage of each active ingredient and total percentage of inert ingredients must appear; or name and percentage of each inert ingredient if preparation is not highly toxic to man. No statement is required if the poison is not highly toxic to man and consists entirely of active ingredients. For arsenicals to be used on foliage, a statement of percentages of total and water-soluble arsenic, each calculated as elemental arsenic, is required. The active ingredient or the analysis, given by most companies, is the most important item of information on a package; it tells the user just what he is getting and how much. Growers should always look for this statement on trade-named products to be sure they are getting what they want. A statement of 100 per cent active ingredients on a container may be misleading, since the law allows any chemical that has some toxic effect on insects to be termed an active ingredient. The basic killing agent may be present in only small quantities in such cases.

5. The net weight and measure of the contents is required. This may be of importance to the user, because time and labor may be saved by purchasing a container holding the weight or volume of material generally used per spray tankful of water. For example, a grower with a 200-gallon-capacity sprayer should purchase a 50 per cent wettable DDT in 4-pound packages because 4 pounds of 50 per cent DDT is the ordinary dosage per 200 gallons of water.

6. If the material is highly toxic to man and animals the label should bear the skull and crossbones, the symbol of poison, and the word POISON prominently in red.

7. An antidote, if known, for the poison or poisons contained must be given.

8. Instructions for use necessary and adequate for the protection of the public should appear on each package.

9. In addition to the labeling requirements given above, packages should carry dilution directions for control of specific pests as well as for pests in general. This information should be followed carefully.

10. Each package also has a non-warranty that protects the manufacturer or seller from damage suits for which the

user alone may be responsible. This non-warranty does not mean that the company does not have confidence in its product and refuses to stand back of it. Products put on the market by reliable companies have generally been thoroughly tested and should perform as stated when directions are followed.

HOW TO SELECT AN INSECTICIDE

The number of insecticides appearing under trade names constantly increases. Many of these products are similar and are effective against many of the same insects, according to the information given on the labels. This is very confusing to the grower who is trying to find the most effective and economical material for a certain insect or groups of insects on his crops. Insects vary greatly in their susceptibility to different chemicals in insecticide formulations. Some plants also react adversely to some ingredients in insecticides. It is of great importance to read all the information on labels carefully and to know what to look for on a label when making a selection.

The analysis or active ingredient statement on a label is of primary importance as a basis of insecticide selection; not the trade name, which is generally of little value. The insecticide companies or formulators use one or more active ingredients, usually selected from a relatively small number of basic insecticides; they mix in some other materials as diluting agents or some that their research men have found will enhance effectiveness; and then they give the mixture a new name to distinguish it from other companies' products that contain the same active ingredients. The result is thousands of trade-named or proprietary insecticides with comparatively few different active ingredients. In order to purchase intelligently the grower should familiarize himself with the characteristics and uses of the basic insecticides and should not worry about trade names as long as well-known, reliable companies have their names or brands on the products. When the name of the active ingredient or ingredients is lacking, it is better not to purchase the product unless experience has shown it to be effective and safe.

Cost is another consideration in the selection of insecticides, all other things being equal. Comparative prices may be very misleading unless one realizes that price comparisons should be computed on the basis of the cost of a unit of diluted spray or dust applied on the crops and not on the basis of the cost of a unit of concentrated material purchased in the store. For example, let us compare two insecticides under different trade names but with the same active ingredients or with different active ingredients allegedly effective against the same insect pests. The first material is priced at $2.00 per gallon, whereas the second sells at $4.00 per gallon. Apparently the second material is twice as expensive as the first. However, the label on the first material states that it must be diluted 1 part to 200 parts of water compared with 1 part to 800 parts of water for the second material. This makes the cost $1.00 for 100 gallons of the first material diluted and $0.50 for 100 gallons of the second material diluted. Actually, here, the apparently more expensive insecticide costs only one-half as much as the apparently less expensive insecticide. The only time a more expensive insecticide is justified on the basis of actual use is when it is more effective on insects or safer as far as injury to man, animals, or plants is concerned.

It is important when selecting insecticides to keep in mind that the susceptibility of some species of insects and plants to insecticides may vary with climate and geographical location. For that reason a material found effective and safe in one part of the country may not necessarily be effective or safe in another part.

STOMACH POISONS

The Arsenicals

The arsenicals used in insect control consist of the arsenite salts and the arsenate salts. Foliage injury is closely related to the solubility of the arsenicals, and their metallic arsenic content is related to their toxicity to insects. In general, the more soluble the arsenical the more apt it is to "burn" foliage, and the higher the arsenic content the more effective it is on insects. The arsenates are less soluble in water than the arsenites and are therefore safer for foliage. Arsenites such as sodium arsenite and white arsenic are made into poison baits because of their greater toxicity to insects. Hydrated lime or zinc sulfate is generally combined with the arsenates in twice the amount of the arsenical in order to reduce the formation of soluble arsenic and in turn prevent the danger of foliage injury. Hard waters that contain alkali or salt increase the solubility of arsenicals, and when employed with arsenicals may injure plants. Plants vary in their sensitivity to soluble arsenic, and some, like peaches, tobacco, and Persian walnuts, are easily injured.

The arsenicals are all poisonous to man and animals and must be applied so that poisonous residues are not present on fruit or vegetables at harvest time. On most fruit at least 6 weeks after the last spray and normal rainfall are necessary for the weathering of the material so that it will fall below the tolerance level. The tolerance for arsenic expressed as arsenious acid is 0.25 grain per pound and for lead (if lead arsenate is used) 0.050 grain per pound. At one time the poisonous residues were removed from apples by running them through a dilute hydrochloric acid solution, but at present non-poisonous or less poisonous insecticides are available for late-season pest control, making washing unnecessary. The ability of arsenicals used in sprays to stay in suspension and their adhesive qualities are characteristics that make some forms better insecticides than others. The fineness of the arsenical is directly related to its ability to stay in suspension.

Arsenicals are generally purchased as wettable powders that go into suspension in water, but some are also available as very finely ground pastes. The cost of both forms is about the same. The wettable powders should first be made into a thin paste in a bucket before being added to the water in the spray tank; better dispersion will be obtained. Arsenicals can also be purchased as dusts containing 10 to 20 per cent of the active ingredients.

The arsenicals are incompatible with hard waters, ordinary laundry soaps, soluble chlorides and carbonates, and high concentrations of lime-sulfur (see compatibility chart, Table 50). These materials increase the solubility of the arsenicals and induce “burning” of the foliage. Applications made during periods of high humidity, prolonged dryness, and high temperatures also tend to injure foliage.

The arsenicals in Table 10, listed in the order of safety to foliage, are the ones commonly used in insect control.

TABLE 10

THE IMPORTANT ARSENICALS AND THEIR USES

Name	Chief Uses	Remarks
Basic lead arsenate	For chewing insects on plants sensitive to arsenicals, such as peaches, tobacco, Persian walnuts	Little used—replaced by newer organics
Standard (acid) lead arsenate	For most chewing insects on fruits and ornamentals	Partly replaced by newer organics
Basic copper arsenate	For same pests as lead arsenate	Has some fungicidal action—scarce and expensive
Calcium arsenate	Substitute for lead arsenate on arsenic-tolerant plants	Cheaper than lead arsenate but more apt to "burn"
Paris green (copper aceto-arsenite)	In poison baits and as a mosquito larvacide	Too soluble for most plants—little used
White arsenic (arsenic trioxide)	In poison baits	Also used in weed control
Sodium arsenite	In poison baits	Also used in weed control

The Fluorine Compounds

The fluorine compounds used as insecticides may be divided into the fluoride salts such as sodium fluoride, barium fluoride, and cryolite (sodium fluoaluminate or sodium aluminum fluoride); and the fluosilicate salts such as sodium fluosilicate and barium fluosilicate. They are all highly poisonous to man and animals, cryolite being the least poisonous. Injury to plants by these salts is directly proportional to their solubility. The fluoride and fluosilicate salts (with the exception of cryolite and barium fluosilicate), because of their solubility, are very injurious to foliage but are widely used in roach powders, poison baits, lice powders, wood preservatives against termites, and mothproofing agents on woollens.

Fluorine compounds used in sprays are deficient in adhesive properties and may produce an accumulative injurious effect on plants after several sprays. The degree of toxicity varies with the plants and with their geographical location. Beans are resistant to injury from fluorine sprays in Tennessee, but they are susceptible in New Jersey. Peaches in some regions may be seriously defoliated by cryolite. The fluorine compounds are decomposed by alkalies and therefore should not be combined with lime, nicotine, Bordeaux mixture, common soaps, or lime-sulfur. They generally offer little or no advantage over the arsenicals from the standpoint of safety to man, animals, and plants; but in some cases they are cheaper and more toxic to insects. The tolerance for fluorine on fruit or vegetables is 0.02 grain per pound.

Cryolite, the most popular of the fluorine compounds for foliage, occurs naturally in Greenland, and it may be manufactured synthetically. Both forms are sold as very fine powders to be diluted as dusts or to be put in water suspension as sprays. There is little difference in their effectiveness on insects. They are commonly used as dusts for various chewing insects on garden vegetables.

Miscellaneous Stomach Poisons

The following compounds are used for specific insect pests with various methods of application:

TARTAR EMETIC (Antimony potassium tartrate). This compound is a white powder, soluble in water and moderately poisonous to man and animals. It is used as an active ingredient in liquid baits attractive to moths, wasps, and yellow jackets. Tartar emetic in combination with sugar has also been found effective as a spray in the control of gladiolus and onion thrips.

THALLIUM SALTS. Two highly poisonous compounds of thallium, thallous sulfate and thallous acetate, have been found effective as an ingredient in poison ant baits and in rodent baits, because they have no warning taste or smell. They require careful use and placement, since beneficial animals and birds may also be killed. A number of commercial ant and rodent baits contain thallium salts.

MERCURY SALTS. Both mercuric chloride (corrosive sublimate) and mercurous chloride (calomel) are widely used for the control of the cabbage maggot and the onion maggot. Mercuric chloride is moderately soluble in water, highly poisonous, and corrosive to metals. It is employed as a drench around the base of plants at the rate of 1 ounce to 15 gallons of water. Calomel is relatively insoluble in water and is mildly poisonous but equally effective. It may be applied to seed coats, dusted on the bases of plants before transplanting, or diluted 1 to 10 with ground limestone and applied to plant bases after transplanting.

SODIUM SELENATE. This compound when added to the soil in small doses has been found to be absorbed in small quantities through the roots of many herbaceous plants without harm to them, and it acts as a stomach poison on insects that feed on the plant juices. This novel method of plant therapy makes it possible for these plants to fight their own insect pests. The method is particularly suitable for herbaceous greenhouse flowering plants. It should not be used with food plants, because selenium is poisonous to higher animals. Sodium selenate is applied to the soil in water solution at the rate of 1/4 to 1/2 gram per square foot or in a commercial pellet form mixed with phosphates at the rate indicated on the label. Certain organic phosphate compounds such as Pestox and Systox have also been found effective as systemic insecticides.

POISON BAITS. The chemicals effective in poison baits are generally too injurious to foliage to be incorporated in sprays or dusts. Many of them are also highly poisonous to man and animals and therefore must be handled with extreme care. Baits are commonly placed where the pests may find them easily. Many poison baits may be purchased ready for use under various trade names; some can be prepared as needed.

A standard poison-bait formula for insects such as grasshoppers, armyworms, and cutworms, with some local variations, consists of the following materials:

Wheat bran	25 pounds
White arsenic	1 pound
Molasses	2 quarts
Water	enough to moisten

The dry ingredients are thoroughly mixed and enough molasses-water mixture is added to moisten the material so that it is crumbly. Ground-up flavoring material such as citrus fruit may be added if it is readily available. Sodium arsenite, sodium fluosilicate, or one of the effective new organic insecticides may be substituted for the white arsenic. This bait, enough for 2 1/2 acres, may be broadcast by hand, with fertilizer spreaders, or with specially built machines from airplanes. For night-feeding insects such as armyworms and cutworms it should be applied in the evening; for day-feeding insects such as grasshoppers it should be applied in the early morning.

Poison baits containing thallium sulfate are most effective against ants, and those containing methaldehyde and calcium arsenate are most effective against slugs or snails.

QUESTIONS FOR DISCUSSION

1. Why has the use of insecticides gained such prominence in recent years?
2. Is the reliance on insecticides as the chief means of insect control a good or a bad thing?
3. In what form is an insecticide generally most effective in enclosed spaces? In open fields? In the soil?
4. Why is the dispersal of insecticides in aerosol form such an outstanding development?
5. Why is plant chemotherapy so promising a method of pest control?
6. What are some of the most important things to look for on the label of an insecticide?
7. May the same type of insecticide be sold under any number of trade names?
8. Does the percentage of active ingredients vary in the same insecticide under different trade names?
9. Is a trade name of much value to a prospective purchaser?
10. Why can one be easily misled if he selects insecticides on the basis of the cost per unit purchased in the store?
11. How can you account for the same insecticide being effective on a pest in one area and ineffective in another?
12. What is the relation between the solubility of arsen-

icals and their injury to foliage?

13. Why is sodium arsenite or white arsenic more toxic to insects than lead arsenate?

14. Why is the use of lead arsenate discouraged on the edible parts of plants, especially near harvesting time?

15. Why is lime generally used with arsenicals in spray mixtures?

16. Do fluorine compounds have any advantages over arsenicals as foliage sprays?

17. Why is it desirable, in poison baits, to use stomach insecticides that would burn foliage?

18. What makes plant therapy with sodium selenate such an effective method of pest control?

19. Of what value is the Federal Insecticide, Fungicide, and Herbicide Act to the user of economic poisons?

20. Do you think the use of insecticides upsets the so-called "balance of nature?" Is destructive to wildlife?

Chapter 8

THE CHEMICAL CONTROL OF INSECTS THE DORMANT AND SUMMER CONTACT INSECTICIDES

DORMANT SPRAYS

Many insect pests and mites overwinter in various dormant stages on trees and shrubs. Dormant-spray applications that permit high concentrations of strong chemicals can control many of these pests much more effectively than the much milder insecticides that must be used during the summer when plant injury must be avoided and when the insects are difficult to reach because of protective foliage. Furthermore, every insect killed before it has a chance to procreate means hundreds fewer potential pests with which to deal during the summer.

PESTS CONTROLLED. The pests that may be controlled by dormant sprays are the numerous species of scale insects; aphids in the egg stage or as newly hatched nymphs; mites in the egg or adult stage; pear psyllids in the adult stage; leaf roller eggs; and other pests that overwinter on the trees where they may be contacted. Dormant sprays are always contact sprays because the pests are in an inactive state and must be contacted to be killed. The sprays should be applied to all parts of trees and shrubs, especially the twigs and undersides of the branches, where the pests are usually found. The dormant sprays should not be applied when it is too windy, when the trees are wet, and when the temperature is near or below freezing.

The two most common types of dormant insecticides are the petroleum oils and the dinitro compounds. Liquid lime-sulfur, once the standard dormant spray, has been almost wholly replaced by the above compounds which are more effective and more agreeable to use.

The Oils

Petroleum oils derived from the lighter lubricating fraction form one of the most important groups of insecticides. They are highly effective for red mite eggs and give good control of most dormant insect stages, except for aphid eggs, that occur on plants. They may be purchased as pure oils to be emulsified with water in the spray tank or as miscible oils or oil emulsions to be diluted with water. Miscible oils are oils plus an emulsifier and have the appearance of the oil. They produce a milky emulsion on dilution with water. Oil emulsions are oils plus an emulsifier plus some water. They appear creamy and also make milky emulsions on dilution. Whether an oil is purchased as a miscible oil or an oil emulsion or is tank-mixed is a matter of comparative toxicities, costs, and preference. Usually tank-mixed emulsions are the most economical.

EMULSIFIERS. Since oils will not naturally mix and stay dispersed in water, substances known as emulsifiers must be used with them. Emulsifiers cause the oil to break up as tiny globules that stay dispersed when they are mixed with water. Emulsifiers are substances that are soluble in both oil and water, in water alone, or at least mix with both as colloidal dispersions. Soaps, gums, albumins, casein products, starches, colloidal clays, and sulfonated vegetable and animal oils are common emulsifiers. Many commercial emulsifiers containing these or other products are on the market. Blood albumin, a by-product of the slaughtering industry, is one of the most effective emulsifiers from the standpoint of maximum oil deposit. Some growers find it more economical to make their own oil emulsions and so purchase their oil and emulsifying agent separately.

TANK-MIXED EMULSIONS. To make a tank-mixed oil emulsion, these steps should be followed:

1. Run about 25 gallons of water into the spray tank.
2. Start the engine, place the ends of the spray guns in the tank, and open them.
3. Sift in the emulsifier (1/2 pound commercial blood albumin per 100 gallons of water).
4. Pour in the oil (3 gallons per 100 gallons of water is the usual dosage, but it may vary from 1 to 6 gallons per 100 gallons depending on the type of oil and the pests to be controlled).
5. Run through the pump for about 2 minutes and then fill the tank with water.
6. Add any other ingredients, if necessary, such as a dinitro compound.

7. Keep the engine running while preparing to spray the emulsion.

SPECIFICATIONS FOR SPRAY OILS. There are three general classes of petroleum oils found in this country: (1) those with a paraffinic base, from the Pennsylvania oil fields; (2) those with an asphaltic or naphthenic base, from the California oil fields; and (3) those with a mixed paraffinic and naphthenic base, mainly from the mid-continent oil fields. Spray oils are made from all three groups, but the more paraffinic an oil the greater its insecticidal effectiveness and the greater its per gallon efficiency.

Two types of paraffinic dormant oils are commonly available on the market in the Eastern United States: the "regular type" of dormant oil of moderate degree of paraffinicity and the "superior type" of dormant oil, more highly refined and more highly paraffinic (Table 11). The naphthenic-based oils are still used on the West Coast because they are more easily available and cheaper. The "superior-type" oils have the advantage over all older oil types in that they are more effective and at the same time safer for apple trees in the green-tip and delayed-dormant stages of bud development, when maximum kill of red mite eggs may be obtained. The lighter the oil within the spray-oil range, the safer it is for oil-sensitive plants. The "superior oils" cost more per gallon but make up for it in greater efficiency and safety. At 3 per cent strength they will control all pests susceptible to dormant oils.

The unsulfonated residue (determined by chemists) is useful in expressing the degree of refining that an oil has undergone, and this in turn determines its degree of safety to plants. The unsulfonated residue is expressed in percentage and is a measure in an oil of the saturated hydrocarbons that do not react or combine with sulfuric acid. It is the unsaturated hydrocarbons that harm plants; therefore, the higher the unsulfonated residue the fewer unsaturated hydrocarbons and the safer the oil.

The Dinitro Compounds

The dinitro compounds, dinitro-*o*-cresol, dinitro-*o*-cyclohexylphenol, their salts (usually sodium or ammonium), and other closely related compounds are yellow, dyelike products

TABLE 11

SPECIFICATIONS OF SPRAY OILS FOR USE ON FRUIT TREES IN THE DORMANT AND SEMI-DORMANT PERIODS

(After Chapman and Pearce, Agr. Chemicals 2:13, p. 19)

Specification	Regular Type	Superior Type
Viscosity (Saybolt, at 100° F.)	90-120 (sec.)	
Viscosity index (Kinematic)	65 (min.)	100 (min.)
Gravity (A. P. I. degrees)	28 (min.)	32 (min.)
Unsulfonated residue (ASTM)	78-85%	90-92%
Pour point	Not greater than 30° F.	
Homogeneity	A relatively narrow-boiling distillate portion of petroleum	

that have gained wide use as dormant sprays because of their toxicity to aphid eggs, some scale insects, and apple scab fruiting bodies in fallen leaves. Some forms are soluble only in oils and are combined with dormant oil sprays, whereas other forms (mainly the salts) are readily soluble in water and may be sprayed as water solutions as well as with oil emulsions. The water solutions are generally safer for trees than the dinitro-oil combinations and may be used for aphid control without serious injury up through the green-tip stage of apple growth.

When both red mite eggs and aphid eggs are numerous on trees, a dinitro-oil combination is effective, or a dinitro spray may be applied a few weeks before the green-tip stage and the oil applied at the green-tip stage. The two separate applications may be necessary in some regions where dinitro-oil combinations have produced injury. The dinitros may be injurious to needled evergreens and are not recommended for them. For the control of some scale insects such as the euonymus scale and the oyster shell scale the dinitros are superior to the oils, but for the San Jose scale and leaf roller eggs the oils are more effective.

AVAILABLE FORMS. The dinitro compounds are obtainable as dry powders to be dissolved in water or in oil emulsions as directed on the label, as thin pastes for dilution with water, or as premixed dinitro-oil combinations for emulsification in water. The dinitros are available under such trade names as Dinitro-Sol, Dinitrol, Krenite, Elgetol, DN Dry Mix, and Dinitro Dry. Dinitro-oil combinations are sold under names such as Dowspray Dormant, Nitro-Kleenup, and Nitro-Vaporal. The dinitros are not disagreeable to handle but are inflammable when allowed to dry on clothing and are poisonous when ingested. They stain woolens yellow but wash out of cottons readily. It is best to wear gloves when spraying, because the yellow stain is difficult to wash off the hands.

Recently the triethanol amine salt of dinitro-o-sec-butyl phenol has been found promising as a completely dormant spray on apples for light infestations of red mite eggs as well as for aphid eggs and other dormant pests. This eliminates the need for separate dinitro and oil sprays or combinations of the two in order to take care of both these pests. It is available under trade names such as Elgetol 318 and DN-289.

THE SUMMER CONTACT INSECTICIDES

The summer contact insecticides for plants in foliage are effective for many chewing insects as well as for sucking forms. In addition, many of them are stomach poisons or repellents.

The Summer Oils

These are highly refined white petroleum oils with an unsulfonated residue of 90 per cent or better and with practically all the unsaturated hydrocarbons removed. This makes them fairly safe on foliage at strengths from .5 to 1.2 per cent actual oil in the spray. Like the dormant oils they may be mixed by the grower as tank-mixed oil emulsions, or he may purchase them as emulsions or as miscible oils. Also, like the dormant oils, the higher their paraffinicity the more toxic they are to insects.

Summer oils may be used alone for the control of some insects and mites, but they are generally combined with other insecticides and fungicides such as nicotine, pyrethrum, rotenone, arsenicals, and ferbam to increase their effectiveness. To avoid plant injury, summer oils should never be combined with any sulfur, nor should they be applied within at least 2 weeks preceding or following sulfur sprays. Spraying with oils under conditions of high temperature and humidity may also lead to plant injury.

Sulfur Compounds

The sulfur compounds such as liquid lime-sulfur, dry lime-sulfur, wettable sulfurs, and sulfur dusts are mainly fungicides, but they have some value in the control of red spider and mites at the same dosages as for disease control. These compounds will be discussed more fully under fungicides in Chapter 18.

The Plant Derivatives

Some of the insecticides derived from plants were employed long before our modern chemicals. Their names and sources are given in Table 12.

TABLE 12

THE PLANT DERIVATIVES AND THEIR SOURCES

Chemical Name	Source	Common and Trade Names
Nicotine (alkaloid)	Leaves and stems of tobacco plants	Free nicotine, Black Leaf 50
Nicotine sulfate	Leaves and stems of tobacco plants	Black Leaf 40, Twenty X-N
Rotenone	Roots of tropical leguminous plants, *Derris*, *Lonchocarpus*, and *Tephrosia* spp.	Derris, cube root, timbo, barbasco
Pyrethrum	Flower heads of some *Chrysanthemum* spp.	Dalmatian Insect Powder, Pyrocide, Stimtox

Table 12 (Continued)

Chemical Name	Source	Common and Trade Names
Hellebore	Roots of liliaceous plants, *Veratrum* spp.	Hellebore
Sabadilla	Seeds of tropical liliaceous plant, *Schoenocaulon* spp.	Sabacide, Sabakill
Ryania	Stems of tropical plant, *Ryania speciosa*	Ryanex
Allyl homolog of cinerin I (*synthetic pyrethrum*)	Synthesized in laboratories	Allethrin, Pyresyn

TOXICITY TO LIVING ORGANISMS. The plant derivatives vary greatly in their toxicity to insects and warm-blooded animals. All but nicotine are safe on plants under the recommended directions. Under hot conditions nicotine may burn tender foliage, especially under greenhouse conditions. All the plant derivatives tend to lose their toxic properties fairly rapidly on exposure to open air; rotenone and pyrethrum lose theirs on exposure to light as well. They should therefore be stored in opaque, air-tight containers. Their relative toxicities and methods of action on insects are given in Table 13.

TABLE 13

TOXICITY AND MODE OF ACTION OF THE PLANT DERIVATIVES

Name	Toxicity to Man	Residual Toxicity to Insects	Mode of Action on Insects
Nicotine (alkaloid)	High (in concentrated solution)	About a day	Contact and fumigant
Nicotine sulfate	High (in concentrated solution)	1-2 days	Contact and fumigant
"Fixed" nicotine	High (in concentrated solution)	About 1 week	Contact and stomach
Rotenone	Very low	About 1 week	Contact, stomach, and repellent
Pyrethrum	None	A few days	Contact
Hellebore	Low	A few days	Contact and stomach
Sabadilla	Moderate	A few days	Contact
Ryania	Low	About 1 week	Contact and stomach
Allethrin	None	A few days	Contact

FORMULATIONS AVAILABLE. Nicotine is available as nicotine alkaloid, a liquid, containing 50 per cent nicotine; and as nicotine absorbed in a combustible material for greenhouse fumigation and sold under the trade name Nico-fume, which gives off a thick cloud of fumes when it is ignited. Nicotine sulfate, a liquid containing 40 per cent nicotine, is the common form of nicotine for spray use on the market. Nicotine is also available in dust form as ground tobacco leaves (approximately 1 per cent nicotine) and as an impregnated nicotine sulfate dust of 1 to 5 per cent. When nicotine sulfate is absorbed in bentonite clay, a "fixed" nicotine that retains its toxicity for several days results.

The remaining plant derivatives are all available as dusts, with varying amounts of active ingredients: rotenone, 1/2 to 1 per cent; pyrethrum, .2 to .4 per cent; allethrin, .5 per cent; sabadilla, 10 to 20 per cent; ryania, 30 to 40 per cent. Rotenone, allethrin, and pyrethrum are available as concentrated liquid extracts for sprays, under numerous trade names. Wettable powders of rotenone (4 to 5 per cent) and of ryania (50 per cent) are also available.

COMPATIBILITY. Rotenone and pyrethrum are both made ineffective by lime or alkaline solutions; nicotine sulfate and sabadilla are both made more effective if hydrated lime is added to dusts or sprays. Nicotine, rotenone, and pyrethrum are compatible with fungicides such as fixed coppers, sulfurs (wettable and dust), and the dithiocarbamates. Rotenone and pyrethrum may also be used in combination with DDT, its close relatives, and lindane. See compatibility chart, Table 50.

USES FOR THE PLANT DERIVATIVES. Although most of the plant derivatives have some effect on insects as stomach poisons and repellents, they are chiefly contact insecticides and should be applied so as to contact the pests. Their uses are given in Table 14.

TABLE 14

CHIEF PESTS CONTROLLED BY PLANT DERIVATIVES

Name	Pests
Nicotine alkaloid	Aphids in greenhouses
Nicotine sulfate	Aphids and other small, soft-bodied insects
"Fixed" nicotine	Codling moth, European corn borer (largely replaced for these by new organics)
Rotenone	Most vegetable pests such as Mexican bean beetle, cucumber beetles, green cabbage worms, thrips
Pyrethrum	Same as rotenone but more effective for cabbage looper, aphids, and leafhoppers
Hellebore	No longer on market (replaced by rotenone and pyrethrum)
Sabadilla	Plant bugs such as squash bug, chinch bug, harlequin bug
Ryania	European corn borer
Allethrin	Same as pyrethrum and rotenone

QUESTIONS FOR DISCUSSION

1. Are dormant sprays more practical than summer sprays for pests that may be controlled by either of them?
2. Is there any difference between the effectiveness of miscible oils and oil emulsions?
3. Explain the action of an emulsifier in preparing an oil emulsion.
4. What are the advantages and disadvantages of using a miscible oil as compared with an oil emulsion?
5. Explain the procedure for preparing a tank-mixed oil emulsion.
6. What relation is there between the paraffinicity of an oil and its safety to plants? Toxicity to insects?
7. What relation is there between the heaviness of an oil and its safety on plants? The unsulfonated residue and its safety on plants?
8. What advantages are there in using a "superior type" oil?
9. Under what conditions is a dinitro spray preferable to an oil spray?
10. When would a combination of an oil and a dinitro compound be preferable?
11. What disadvantages are there in the use of dinitro sprays?
12. How do summer oils differ from dormant oils?
13. Why is rotenone most useful on the home grounds and in vegetable gardens?
14. Why should the plant derivatives be kept in tightly closed containers?
15. Why can nicotine be used on plants within a few days of harvest although it is a deadly poison?
16. Why are insect eggs easier to control on dormant plants than on growing plants?

Chapter 9

THE CHEMICAL CONTROL OF INSECTS FUMIGANTS AND SPRAY SUPPLEMENTS

Fumigants are those chemical compounds that while in a gaseous state are capable of destroying insects and other forms of life. Many of the insecticides that are stomach and contact poisons also have some fumigating action or can be applied as fumigants with the proper treatment. Fumigants may be solids or liquids when purchased, but if they are solids or liquids they must volatilize or be made to volatilize readily.

There are three ways of employing fumigants: (1) to disinfest plants or foodstuffs in enclosed places such as greenhouses, granaries, and mills; (2) to destroy organisms in the soil; or (3) on outdoor plants or crops, provided that the gases can be confined long enough to produce lethal effects on the insects.

PRECAUTIONS. Most fumigants are highly toxic to warm-blooded animals and must be used with proper precautions, especially indoors. In some cases, as in cyanide fumigation, gas masks are essential to the safety of the operators. The directions on the container should always be followed with respect to safety of plants, handling, preparation, spilling on skin or clothes, inhaling of fumes, etc. In soil fumigation the preparation and after-treatment of the soil are important items.

Temperature is a major factor in the effectiveness of fumigants. Most fumigants are ineffective at temperatures below 65° F. and are apt to injure plants at too high temperatures (90° F. or above). A temperature of about 75° F. of either air or soil is probably optimum for most fumigation work. Too high relative humidities of the air and dropping temperature when plants are fumigated may lead to condensation of moisture and plant “burning.” Soil should be in good working condition for the best fumigating conditions.

DOSAGES. The dosages for fumigants within enclosed spaces are usually calculated in terms of pounds or ounces per unit of cubical space, such as ounces per 1000 cubic feet. The dosages of soil fumigants are usually calculated in grams, ounces, or milliliters per square foot or in pounds per acre. Soils high in organic matter or heavy soils generally require heavier dosages for effective control than light soils. Generally in soil fumigation more than the minimum dosage rate recommended by the manufacturer should be used for effective results.

SOIL FUMIGANTS

CHOICE OF A FUMIGANT. In soil fumigation the choice of a fumigant will depend on factors such as pests to be controlled; the amount, location, and temperature of the soil; the availability of water for a prompt seal; and the cost and availability of the materials. The usual injection depth of most soil fumigants is from 4 to 8 inches. The chemicals that are generally used in soil fumigation are chloropicrin, DD (dichloropropene and dichloropropane), methyl bromide, and ethylene dibromide—all liquids that vaporize readily and leave no harmful residues in the soil. Some of the new organics such as benzene hexachloride, chlordane, and parathion also have a fumigating action in the soil. These along with DDT will control most soil insects much more cheaply than the above fumigants, but they will not control nematode worms.

PESTS CONTROLLED. Chloropicrin gives nearly complete soil sterilization, destroying soil insects, nematode worms, disease organisms, and weed seeds. DD mixture and methyl bromide readily penetrate unrotted nematode galls, killing all stages. Methyl bromide in enclosed places is a good weed-seed killer and is also a good soil fungicide, but four to five times the usual dosage is necessary under confined conditions for effective fungicidal action. Carbon disulfide as a soil fumigant for insects has been largely replaced by the newer fumigants and by organic insecticides. The conditions of usage for the soil fumigants in nematode control are given in Table 15, and the pests controlled are given in Table 19.

PLANT FUMIGANTS

The fumigants that are safe to use on plants are listed in Table 19. Greenhouse fumigants such as cyanide gas and nicotine have been largely replaced by the new organics in aerosol form because of their greater effectiveness. Fumigants that can be confined for sufficient periods are effective

TABLE 15

SOIL FUMIGANTS AND THEIR USAGE IN NEMATODE CONTROL

Name	Dosage (per acre)	Cost (per acre)	Minimum Soil Temperature	Water Seal	Waiting Period (after treatment)
Chloropicrin	500-700 lb.	About $500	65° F.	Yes	1-2 weeks
DD	200-400 lb.	Less than $80	38° F.	Advisable	2-4 weeks
Methyl bromide	480-580 lb.	More than $100	50° F.	Yes	2-8 days
Ethylene dibromide	20-40 gal. (10% V/V)	Less than $80	45° F.	No	10-15 days

TABLE 16

NUMBER OF GALLONS OF ANY FUMIGANT REQUIRED TO TREAT 1000 SQUARE FEET*

At these spacings of injections	At these millimeters per injection						
	1	2	3	5	7	8	9
6 in.	1.06	2.11	3.17	5.28	7.40	17.74	9.51
8 in.	0.66	1.32	1.98	3.17	4.62	5.28	5.94
10 in.	0.40	0.79	1.19	1.98	2.77	3.17	3.57
12 in.	0.29	0.58	0.61	1.45	2.03	2.32	2.62

*Based on 4400, 2500, 1600, and 1100 injections at each of the 4 spacings indicated, which is approximately 10 per cent above the minimum theoretical numbers required. Experience has dictated that extra-marginal injections are often advisable (after Newhall and Lear, Cornell Expt. Sta. Bull. 850).

TABLE 17

FACTS AND SUGGESTIONS TO AID IN THE PURCHASE AND USE OF SOME FUMIGANTS

Trade Name	Lb. per gallon	Ml. per pound	Suggested Dosage Rates	
			per 1000 sq. ft. (gallons)	per acre (gallons)
Chloropicrin	13.8	273	1.0—1.3	40-50
Larvacide	13.8	273	1.0-1.3	40-50
DD mixture	9.9	378	0.7-1.0	30-40
Dowfume N	9.9	378	0.7-1.0	30-40
Garden Dowfume	7.1	530	1.5-2.0	60-80
Dowfume W-40	8.9	428	0.4-0.6	15-20
Iscobrome D	7.7	494	0.7-1.0	30-40
Iscobrome	8.3	456	2.0-2.5	100
Dowfume G	11.3	334	2.0-2.2	90

(After Newhall and Lear, Cornell Expt. Sta. Bull. 850.)

TABLE 18

SOME USEFUL CONVERSION MEASUREMENTS

	Injections (per 1000 sq. ft.)	(per acre)
On 8-inch centers	2450	100,000
On 10-inch centers	1600	64,000
On 12-inch centers	1100	44,500

Feet in 1 mile	5,280
Square feet in 1 acre	43,560
Square inches in 1 acre	6,272,640
Millileters (cc.) in 1 teaspoon (approx.)	5.0
Millileters (cc.) in 1 tablespoon	15.0
Millileters (cc.) in 1 fluid ounce	29.6
Millileters (cc.) in 1 pint	473.2
Millileters (cc.) in 1 quart	946.3
Millileters (cc.) in 1 gallon (U.S.)	3,785.4
Cubic feet of soil in 1 bushel	1.25

(After Newhall and Lear, Cornell Expt. Sta. Bull. 850.)

on outdoor crops, for example, when hydrocyanic acid gas for scale insect control on California citrus is confined in tents erected over the trees (Fig. 62). On low-growing crops fumigation may be accomplished by dragging a long, light tarpaulin behind the fumigator to keep the fumes down. This method has been successful with nicotine fumigation for aphids on peas and other crops. Methyl bromide as a fumigant for insects on greenhouse plants is practiced mainly in fumigation chambers because it is too costly and escapes too easily for use on a greenhouse scale.

STORED-PRODUCTS FUMIGANTS

The fumigants for stored products such as grains and other foodstuffs must be penetrating, must be harmless to the seed, and must not affect the quality of the flour. Fumigants that are heavier than air, such as carbon disulfide and methyl bromide, may be placed on the top of the grain in small bins to settle slowly down to the bottom. In the case of grain stored in huge bins or grain elevators the fumigant is usually mixed with the grain as it flows into the storage bins. Carbon tetrachloride is generally used with fumigants such as carbon disulfide and ethylene dichloride to reduce the danger of fire or explosion, both these compounds being highly inflammable or explosive.

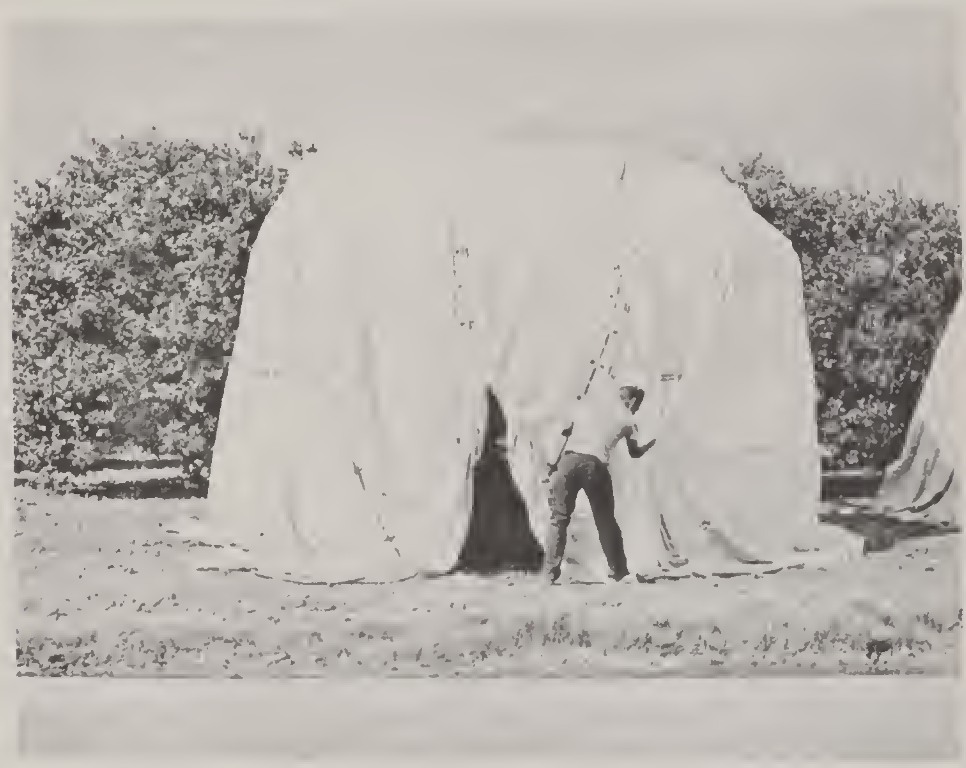


FIG. 62. Tent erected over citrus tree for fumigation. The bottom is sealed with soil. Markings on tent are for determining cubical contents (courtesy of the American Cyanamid Co.).

SPRAY SUPPLEMENTS

A spray supplement or spray adjuvant may be defined as any substance that when combined with an insecticide enhances its sticking, spreading, or wetting qualities, makes it safer, aids in its dilution or uniform dispersion, or increases its toxicity to pests. Spray supplements may be divided into adhesive or sticking agents, wetting and spreading

TABLE 19

FUMIGANTS AND THEIR USES

Soil Fumigants

Name	Common and Trade Names	Chief Uses
Chloropicrin	Larvacide, tear gas	Gives nearly complete soil sterilization
DD	DD Mixture, Dowfume N	Nematodes, wireworms
Methyl bromide	Iscobrome, Dowfume MC-2, Dowfume G	Nematodes, soil insects, weed seeds, fungi
Ethylene dibromide	Iscobrome D, Garden Dowfume, Soilfume, Bromofume 40, Dowfume 40	Nematodes, soil insects
Carbon disulfide	.....	Soil insects
	Plant Fumigants	
Hydrocyanic acid gas	Cyanide gas, hydrogen cyanide	Tent fumigation of citrus trees, greenhouse pest fumigation
Calcium cyanide	Cyanogas	Greenhouse pes fumigation
Nicotine (alkaloid)	Nico-Fume Pressure Fumigator	Greenhouse aphids
Methyl bromide	Iscobrome, Dowfume G	In fumigation chambers for most greenhouse pests
Naphthalene	Fulex	Red spider mite in greenhouses

Table 19 (Continued)

Name	Common and Trade Names	Chief Uses
Paradichlorobenzene	PDB, para crystals	Peach tree borer around bases of peach trees
Azobenzene	Benzo-Fume, Azofume	Red spider mites in greenhouses
Ethylene dichloride	Di-chlor Emulsion	Peach tree borer around bases of peach trees
Propylene dichloride emulsion	.....	Peach tree borer around bases of peach trees

Stored-Products Fumigants

Name	Common or Trade Names	Chief Uses
Hydrocyanic acid gas	Hydrogen cyanide, Zyclon Discoids	Stored-product pests in mills, warehouses, granaries
Calcium cyanide	Cyanogas	Stored-product pests in mills, warehouses, granaries
Chloropicrin	Larvacide, tear gas	Stored-grain pests in granaries and mills
Methyl bromide	Iscobrome, Dowfume G	Very penetrating; for stored-food pests in granaries, mills, warehouses

Table 19 (Continued)

Name	Common and Trade Names	Chief Uses
Ethyl oxide 10% Carbon dioxide 90%	.....	Stored-grain pests
Carbon tetrachloride 80% Carbon bisulfide 20%	.....	Stored-grain and mill pests
Ethylene dichloride 75% Carbo tetrachloride 25%	.....	Stored-grain and mill pests
Ethylene dichloride 20% Carbon tetrachloride 70% Ethylene dibromide 10%	.....	Stored-grain and mill pests
Naphthalene	Naphtha flakes, moth flakes	Fumigant for clothes moths
Paradichlorobenzene	Para Crystals, PDB	Fumigant for clothes moths

agents, emulsifying agents, deflocculating agents, synergists, safeners or correctives, and diluents or carriers.

STICKING AGENTS. These materials have the function of increasing the retention of spray or dust deposits on plants by resisting the various factors involved in weathering. The oils in the form of liquid soaps or emulsions, including fish oils, vegetable oils, and mineral oils, form an important group of stickers. They are generally used for this purpose at rates from 1 pint to 4 pints per 100 gallons of spray. Other stickers are proteinaceous materials such as milk products, wheat flour, soybean flour, gelatine, glue, blood albumin, and calcium caseinate. These are used at rates of 1/2 to 4 pounds per 100 gallons of spray depending on the material and on directions on the container. Gums, rosin, and fine clays may also be employed as adhesives. Stickers that also have wetting and spreading ability are combined mainly with stomach poisons, residual contact insecticides, and fungicides. A large number of stickers that are also spreaders and wetters are sold under trade names and may consist of salts of sulfated alcohols, sulfates of fatty alcohols, esters of fatty acids, alkyl sulfonates, and petroleum sulfonates, as well as the substances previously mentioned.

SPREADERS AND WETTERS. A material that is a good spreader is commonly a good wetter, and vice versa. The terms imply that they aid liquid sprays in spreading evenly over a surface and wetting it. Wetting must always take place before good spreading can be obtained. Spreaders and wetters act by lowering the surface tension of the water in which they are dissolved. Potassium soaps and proteinaceous products are found in many spreaders and wetters. Most of the stickers discussed in the previous section are good spreaders and wetters also and generally all three characteristics are of value in a spray material. Excessive amounts of a spreader and wetter in a spray solution will cause excessive runoff of the spray and a poor deposit. Directions on containers should be carefully followed.

EMULSIFYING AGENTS. These materials aid in keeping oil particles as colloidal suspensions in water. Most spreaders and wetters also make good emulsifiers, but some may produce more stable emulsions than others. Blood albumin, sulfonated petroleum products, and vegetable or animal oil soaps make good emulsifiers. Bordeaux mixture, clays, and milk products are also common emulsifiers. "Quick-breaking" emulsions produce better spray deposits than more stable emulsions. (See the section on emulsifiers in Chapter 8.)

DEFLOCCULATING AGENTS. These are materials that are added to insecticide suspensions in water to prevent rapid settling. Proteinaceous materials mentioned previously may be used for this purpose. The more finely ground an insecticide the less need there is for a deflocculating agent.

SYNERGISTS. These are materials (they may also be insecticides) that increase the toxic effect of insecticides or fungicides. Their use may permit a reduction in the amount of active ingredient in a spray while its effectiveness is maintained and its cost is reduced. Many substances such as oils and spreaders and wetters that are combined with insecticides may be classed as synergists. Sesame oil, N-propyl isome, and piperonyl cyclonene have been found to be synergists for pyrethrum, whereas chlordane, piperonyl cyclonene, and piperonyl butoxide are reported to act as synergists in low-strength rotenone dust mixtures. Hydrated lime may be considered a synergist for sabadilla and nicotine sulfate. Both piperonyl cyclonene and piperonyl butoxide have considerable insecticidal value themselves, and since they are non-poisonous to warm-blooded animals they may have considerable value where such insecticides are required.

SAFENERS OR CORRECTIVES. These are substances that are added to sprays to reduce the danger of foliage injury. They act as buffers or form harmless chemical combinations where pest-control chemicals are likely to break down and produce injurious substances. Hydrated lime or lime and zinc sulfate combined are safeners for the arsenicals. The zinc sulfate-lime formula for apples is 2-4-100 and for peaches is 6-8-100. Commercial zinc-hydrate is sold under the trade name Safe-N-Lead for use with lead arsenate at the rate of 1 pound per 100 gallons of spray for apples and 2 pounds per 100 gallons of spray for peaches. Sulfur may be used as a safener with toxaphene on some plants such as peaches.

DILUENTS OR CARRIERS. A diluent or carrier may be any material to dilute or decrease the amount of active ingredient in any spray or dust. In sprays, water or oils are the usual diluents. In dusts, a number of different, finely ground diluents that occur naturally may be used. These diluents are classified in Table 20.

These dust diluents should flow freely, disperse readily, adhere to plant surfaces well, and be chemically inert. In addition they should be non-abrasive. Their bulk densities, which are an indication of their settling rates, vary from 11 pounds per cubic foot (Celite) to about 60 pounds per cubic foot (Florida limestone). The silicates are intermediate, varying from 30 to 45 pounds per cubic foot. Most of the diluents for dusts are ground so fine that 80 to 100 per cent of the particles pass through a 325-mesh screen (0.83 to 3 microns particle size). Different diluents may influence the effectiveness of insecticides and fungicides quite markedly. Alkaline diluents generally should not be employed with the insecticides that are not compatible with alkalis (Table 50) but are best for making nicotine dusts. Pyrophyllite as a diluent for rotenone dusts has been shown to give better results than talcs or clays. Sulfur is valuable both as a diluent and as a fungicide in many dust formulations. Medium weight dusts

(35-45 lb. per cu. ft.) are preferred for ground-operated power dusters, but heavy dusts (45-60 lb. per cu. ft.) are preferred by airplane or helicopter operators.

TABLE 20

DILUENTS OR CARRIERS

Aluminum Silicates

Bentonite
Cherokee clay
Continental clay
Feldspar
Frianite
Fuller's earth
Kaolin
Pyrophyllite

Magnesium Silicates

Talc
Soapstone

Diatomaceous Silicas

Celite

Alkaline Inorganics

Hydrated lime
Dolomite
Limestone
Florida limestone

Neutral Minerals

Gypsum (calcium sulfate)
Sulfur

Botanical Flours

Walnut shell flour
Soybean flour
Redwood bark flour

QUESTIONS FOR DISCUSSION

1. Are there any advantages in using a fumigant in place of a spray or a dust under conditions where either can be used?
2. Why do heavy soils high in organic matter require heavier dosages of a fumigant for effective control than light soils?
3. What are the important factors to be considered in soil fumigation?
4. Why is the use of fumigants in greenhouses being discarded?

5. Why hasn't soil fumigation been practical on large areas for soil insect control?

6. Why must a fumigant be quick acting to be effective under outdoor conditions?

7. What properties are desirable in fumigants for use on stored products?

8. Under what conditions would a sticker in a spray mixture be undesirable?

9. Is a spreading and wetting agent more valuable in a stomach insecticide or in a contact insecticide?

10. Of what value are synergists to insecticide manufacturers? To growers ?

11. Does it make any difference what diluent is used to make up a dust? Explain.

12. Under what conditions would a quick-settling dust be useful? A slow-settling dust?

Chapter 10

THE CHEMICAL CONTROL OF INSECTS
THE NEW SYNTHETIC ORGANIC INSECTICIDES

The new synthetic organic insecticides that have appeared on the market are the chlorinated hydrocarbons and the phosphorus compounds. The chlorinated hydrocarbons include (1) dichloro-diphenyl-trichloroethane or DDT; (2) dichloro-diphenyl-dichloroethane or DDD; (3) methoxychlor, the methoxy analog of DDT; (4) hexachlorocyclohexane (benzene hexachloride) or BHC, which has a remarkably strong, persistent, disagreeable odor; (5) the pure gamma isomer of benzene hexachloride or lindane; (6) chlordane; and (7) chlorinated camphene or toxaphene. The phosphorus compounds include (1) tetraethyl pyrophosphate or TEPP; (2) hexaethyl tetraphosphate or HETP (contains 10-20 per cent TEPP); and (3) the thiophosphate compound or parathion, which has a strong, disagreeable odor.

PRECAUTIONS. The growers that use these new insecticides should keep in mind that there is still much to be learned about most of these insecticides. Most are highly specific for some pests and ineffective for others. All are more or less poisonous to warm-blooded animals and are cumulative in the body or have cumulative, injurious effects so that spray residues should be avoided on harvested crops. Some may accumulate in the soil. Some have an offensive odor and may give foodstuffs an off-flavor or taste. Some, like the phosphorus compounds, may produce toxic symptoms or death when applied to the skin or inhaled. Growers should not be frightened away from the chemicals because of these dangers but before using them should become familiar with their properties in order to handle them competently. These new chemicals, if used correctly, are valuable additional weapons in the battle against insect pests.

TOXICITY TO WARM-BLOODED ANIMALS. The relative acute oral toxicity to rats of these new organic insecticides compared to DDT is given in Table 21. In this table DDT is given the value of 1, and the other compounds are given numbers that represent the number of times they are more or less toxic than DDT. DDT is considered to have moderate acute oral toxicity, requiring a mean lethal dose of 250 mg.

per kilo of body weight to cause death in rats. Most of the new organics, especially the phosphorus compounds, may be absorbed through the skin and cause poisoning. Repeated daily exposures greatly increase over one single exposure the danger of absorbing toxic amounts, because much smaller quantities are needed cumulatively to produce toxic symptoms.

Methoxychlor and TEPP do not create a residue hazard: methoxychlor because it has such a low order of toxicity and TEPP because of rapid loss of toxicity (within a day or two) —it is hygroscopic and is rapidly hydrolized. The other compounds present more or less of a residue hazard depending on their toxicity and speed of weathering: they may accumulate in the body like DDT and its relatives, or they may have a cumulative injurious effect like the phosphorus compounds. The organics are also highly toxic to fish and other water-inhabiting organisms and should be used with care around

TABLE 21

RELATIVE ACUTE ORAL TOXICITIES OF THE NEW ORGANICS AND OTHER INSECTICIDES

(After A. J. Lehman, "The Toxicology of the Newer Agricultural Chemicals," Assoc. Food & Drug Officials U. S. Quart. Bull. 12:3, pp. 82-89, 1948.)

Insecticide	Toxicity
DDT	1
Methoxychlor	1/24
DDD	1/10
Pyrethrins	1/6
Chlordane	1/2
Lead Arsenate	1/2*
Lindane	2
Rotenone	4
Toxaphene	4
Nicotine	25
Parathion	70
TEPP	125

*This figure (after Kuhn, Trans. IV, Intern. Entomol. Congr., pp. 673-674, 1929) is based on dogs, which do not vary greatly from rats in susceptibility to lead arsenate poisoning.

pools, streams, and lakes. The only tolerance established for residues has been for DDT—5 parts per million are allowed on apples and pears. Food for canning or processing should be free of all organic insecticide residues. Benzene hexachloride (BHC) and to a lesser extent chlordane when used in soils may produce off-flavor in vegetables. Benzene hexachloride has also produced off-flavor in canned peaches, but the fresh or frozen peaches do not show this off-flavor unless the BHC is applied shortly before harvest. Lindane, the pure gamma isomer of BHC, is practically odorless and is reported not to have the disagreeable properties of BHC.

FORMULATIONS AVAILABLE. All these organic insecticides except TEPP and HETP are available as wettable powders, usually containing 25 to 50 per cent of the active ingredient. Parathion wettable powder contains 15 per cent of the active ingredient, and benzene hexachloride wettable powder contains along with other isomers from 5 to 12 per cent gamma isomer, the actual toxic ingredient. Lindane contains 25 per cent of the pure gamma isomer only. TEPP and HETP are available as water-miscible liquids containing from 20 to 40 per cent of the active ingredient. HETP is considered the same as TEPP in all further discussions, since it contains TEPP as the actual toxic ingredient. All the organics are available as dusts or can be made into dusts containing from 0.5 to 10 per cent of the active ingredient. DDT, lindane, and chlordane are also available as 20 to 50 per cent solutions in emulsifiable oils for plant spraying and as solutions in a refined kerosene oil base for household-pest control. All the chemicals may be used as toxic ingredients in aerosol bombs, but at present DDT, TEPP, and parathion are most commonly employed. Some of the organics such as DDT or chlordane may be on the market mixed with fertilizers for control of soil insects. All the above formulations are available under numerous trade names.

SAFETY TO PLANTS. The safety of the new organics to plants varies with the chemicals, their formulations, the plants, and the weather. In general, the wettable powders and dusts have a greater margin of safety on plants than the emulsifiable oil formulations. The new organics show a high degree of safety on most plant species at the recommended dosages, but some species or varieties, for example in the cucurbit family, may exhibit marked injury such as "burning" or stunting after treatments. This toxicity to the members of the cucurbit family, such as acorn squash and cucumbers, is exhibited mainly by DDT, benzene hexachloride, and toxaphene. The pure grade of DDT, methoxychlor, and lindane are reported to be quite safe. TEPP is reported to be injurious to tomatoes and cyclamens and parathion to McIntosh and related varieties of apples. High temperatures and adverse weather conditions may cause injury with any of the compounds. DDT does not leach out of the soil or decompose readily; thus a toxic amount may be built up in the soil through repeated applications.

COMPATIBILITY. Most of the new organic insecticides appear to be incompatible with alkalies or with alkaline solutions, rapid decomposition taking place. They have, however, been effective with Bordeaux mixture, providing an excess of lime is not used and the insecticide is not added until ready to spray. They all appear to be compatible with sulfur, the fixed coppers and ferbam (Table 50) in plant disease control. Some reports have indicated that roses have been injured by parathion treatments when sulfur residues were present on the foliage. Chlordane, benzene hexachloride, TEPP, and parathion are compatible with DDT and may be combined with it. Pyrethrum is often used with DDT to produce a quick knock-down.

MODE OF ACTION. The superiority of DDT and most of the other new organics to the older insecticides lies in their effectiveness not only as stomach and contact poisons but also as residual contact poisons that kill many insect species by means of a slow paralysis after their feet have contacted the residues. Under outdoor conditions DDT stays effective for 2 to 3 weeks; but under indoor conditions where heavier applications are made it may kill insects such as flies and mosquitoes for 6 months or more. Both DDD and methoxychlor are similar to DDT in their mode of action. Chlordane is intermediate between DDT and benzene hexachloride in residual toxicity—the latter material is effective up to about a week under outdoor conditions. TEPP has only contact effectiveness and must hit the insects. DDT, DDD, methoxychlor, and toxaphene are slow in their toxic action, but the rest give a fairly rapid knock-down. Parathion, although quite volatile, and toxaphene may have a residual effect up to 2 weeks under outdoor conditions. In addition to stomach and contact effect, benzene hexachloride, lindane, and parathion also have considerable fumigating action, which adds greatly to their effectiveness in enclosed places. The available emulsifiable forms of the organics are generally more effective on insects than the corresponding wettable powders.

THE CHLORINATED HYDROCARBONS

USES FOR DDT. DDT may be used as a household insecticide, a soil insecticide, and a plant insecticide for numerous insects of both the chewing and sucking types:

Outstanding for

- Codling moth
- Oriental fruit moth
- Japanese beetle
- Soil insects (25 lb. per acre)
  - Japanese beetle grubs
  - Chinch bugs
- Leafhoppers
- Tarnished plant bug
- Colorado potato beetle
- Cabbage worms
- Corn earworm
- European corn borer
- Chrysanthemum midge
- Boxwood leaf miner
- Most foliage-chewing pests
- Flies
- Mosquitoes
- Lice
- Most pests affecting man, animals, and stored products.

Resistant to DDT

- Mexican bean beetle
- Plum curculio
- Pear psylla
- Boxwood psylla
- Root maggots
- Cabbage aphid
- Woolly aphids*
- Pharoah's ants
- California red scale
- Apple aphids*
- Mealy bugs*
- Mites*
- Spiders
- Snails

*May be encouraged because DDT kills their natural enemies.

There is some evidence that strains of flies and mosquitoes resistant to DDT have developed through its continuous use. Exterminators have reported failures to get fly control in many places where good control was previously obtained. Tests in laboratories have shown that these flies are actually highly resistant to DDT and that this resistance is retained by their offspring for a number of generations. There have been some reports also that leafhoppers are not as readily killed by DDT as formerly—it is entirely possible that other insects may develop strains resistant to one or more insecticides.

USES FOR DDD AND METHOXYCHLOR. Both these new insecticides are valuable for many of the same insects as DDT. In general, they show lesser effectiveness than DDT for most pests. Methoxychlor as a 10 per cent dust has been reported equal to a 1 per cent rotenone dust in Mexican bean beetle control and as a spray is highly effective against the plum cureculio. DDD is most effective in the control of the red banded leaf roller. The chief advantage of these two insecticides over DDT for most pests is their lower toxicity to warm-blooded animals and their relative safety to cucurbits.

USES FOR BHC AND LINDANE. Although BHC is more toxic than DDT to some insects, its use is limited because of its persistent odor and tendency to produce off-flavor in fruits and vegetables. Lindane does not have these disagreeable properties and may be used in the same ways as DDT. Lindane, however, lacks the much longer residual effect of DDT and is more expensive.

Outstanding for

Many foliage-chewing and sucking pests
Wireworms (1 to 2 lb. gamma isomer per acre)
Corn rootworm
Cotton boll weevil
Aphids
Grasshoppers (.5 to .6 lb. gamma isomer per acre)
Flies, mosquitoes, and many other household and barn pests
Seed-corn maggot (combined with Arasan + 4 per cent Methocel: 1 oz. + 1.3 oz. + 1/2 pt. respectively per bushel of seed, applied to seed coats)
Crickets
Plum curculio (on peaches)
Asparagus beetles
Thrips
Mites that cause mange and scabies on animals

USES FOR CHLORDANE. This chemical has been found to be as effective as DDT for most pests and is especially effective on soil-inhabiting insects. Like BHC, it has been found to produce some off-flavor in potatoes grown on soil treated with it.

Outstanding for

- Cockroaches
- Ticks
- Chiggers
- Most household and livestock pests (including mange caused by mites)
- Grasshoppers (1 to 1 1/2 lb. per acre)
- Soil insects (3–10 lb. per acre)
  - White grubs
  - Mole crickets
  - Wireworms
  - Chinch bugs
  - Ants
- Cotton boll weevil
- Birch leaf miner
- Plum curculio
- Squash bug

USES FOR TOXAPHENE. Toxaphene is one of the cheapest of the new organic insecticides and one of the least toxic to honey bees. It does not build up in the soil through repeated applications, because it is decomposed by soil organisms; therefore it appears to have some advantages over some of the other new organics. It has been widely used on cotton as a dust, since it controls most of the important pests.

Outstanding for

- Cotton pests
  - Cotton bollworm
  - Cotton boll weevil
  - Southern green stink bug
  - Cabbage looper
  - Cotton aphid
  - Cotton leafworm
  - Cotton fleahopper
- Grasshoppers (1 1/2–2 lb. per acre)
- Mormon crickets
- Fall armyworm
- Salt marsh caterpillar
- Hornworms

THE PHOSPHORUS COMPOUNDS

USES FOR HETP AND TEPP. This phosphorus compound has uses similar to those for nicotine sulfate but is much more effective.

Outstanding for

Aphids
Mites or red spider (not their eggs)
Many other soft-bodied insects

USES FOR PARATHION. Parathion gives as good or better control than DDT of the same pests and in addition is effective on many that are not readily controlled by DDT. If it were not for its high toxicity to warm-blooded animals it would be the outstanding insecticide today for most insect pests and for mites.

Outstanding for

Aphids
Mites or red spider (including eggs), but not the spruce mite
Woolly aphids
Mealy bugs
European corn borer
Mexican bean beetle
Red banded leaf roller
Oriental fruit moth
Peach tree borer
Grasshoppers (0. 2-0. 3 lb. per acre)
Armyworms
Nearly all greenhouse pests
Meadow nematode on boxwood
Foliar nematode on chrysanthemums
Plum curculio
Birch leaf miner
Boxwood leaf miner
San Jose scale

SOME NEWER ORGANICS

Two new chlorinated hydrocarbons that have been given the coined common names, aldrin and dieldrin, show considerable promise as insecticides. They both rank close to toxaphene in acute oral toxicity to rats and must be handled with extreme care. Under normal outdoor conditions aldrin volatilizes within a week, but dieldrin retains its residual effectiveness for long periods. Neither substance loses its effectiveness in the presence of lime or other alkalies. The formulations are the same as those of the other hydrocarbons. Aldrin is outstanding for soil insects such as wireworms, ants, root maggots, root aphids, and many species of grubs (2 to 5 lb. per acre); grasshoppers (2 to 4 oz. per acre); cotton boll weevil; plum curculio; alfalfa weevil; thrips; and the larvae and adults of flies and mosquitoes. Dieldrin is highly effective against the same pests and some others, but it should be limited to the control of pests where a long residual action is an advantage and its residue does not create a health hazard.

A nitroparaffin compound known as Dilan has been reported to be one-half as toxic as DDT to animals and to be outstanding for Mexican bean beetles, potato insects, and many others.

ACARICIDES (Miticides). A number of synthetic organic compounds for the control of mites or red spider, to be applied as aerosols or as sprays, are on the market. These may be divided into phosphate compounds and non-phosphate compounds. The phosphate compounds consist of trade-named products such as Pestox, Systox, Ovotran, EPN, Metacide, and Dithiono. In general they are much less toxic to warm-blooded animals than parathion and TEPP, but they still must be used with considerable care. Most of these compounds are also effective for aphids and many other pests. Both Systox and Pestox show some promise as systemic insecticides for aphids, mites, and other sap-suckers. The non-phosphate compounds such as Dimite, Aramite, and Karathane are relatively safe to use with ordinary precautions. Dimite, EPN, and Ovotran have good residual action on mites. The remainder give good initial kill but vary from fair to poor in residual action.

ORGANIC THIOCYANTES

Organic thiocyanates sold under trade names such as Lethane, Loro, and Thanite were widely used during World War II as substitutes for scarce insecticides such as nicotine, rotenone, or pyrethrum. They were found effective as contact sprays or dusts for the small, soft-bodied insects. Thanite and Lethane are also valuable as ingredients in fly sprays to produce a rapid knockdown. The use of these compounds is limited at present, because nicotine, rotenone, and pyrethrum are no longer scarce and because of the superiority of some of the new organics.

QUESTIONS FOR DISCUSSION

1. The new organics are better than most of our older insecticides. Why?
2. Is there any justification for the claim that some of the new organics are detrimental to wildlife?
3. Nicotine sulfate in concentrated form is just as deadly a poison or more so than some of the new organics. Why aren't people afraid to use it?
4. What dangers are there to operators using the new organics?
5. Has DDT created other pest problems after apparently solving a number of them?
6. Many of the organics may be obtained as wettable powders or as emulsifiable solutions. Which is best for use on crops? On ornamentals?
7. Why should lime be left out of spray mixtures containing the new organics? Can they be used with Bordeaux mixture, which contains lime?
8. The new organics may vary greatly in their effects on different insects. Can you offer any reasons for this?
9. How do DDT and some of the closely related compounds kill insects?
10. In what ways has DDT proved disappointing?
11. What are the advantages of lindane over BHC?
12. For what types of pests is chlordane very effective?
13. Does toxaphane have any advantages over the other new organics?

14. Why is it considered an advantageous characteristic for TEPP to lose its toxicity readily after application?

15. Why is parathion outstanding as an insecticide?

16. The Mexican bean beetle is resistant to many insecticides. Can you offer any explanation for this?

17. What determines whether a chemical should be applied to the top of foliage only or to both sides?

18. Explain how the continuous use of an insecticide may lead to the creation of a resistant strain of insects from a once highly susceptible one.

Chapter 11

MAMMALS AND BIRDS INJURIOUS TO AGRICULTURE

MAMMALS

There are approximately 20,000 known species of mammals in the world, with about 1500 known in North America. Of these 1500, some 300 species may be injurious at times to horticultural crops. The majority of these 300 species are known as rodents (order Rodentia); some are known as rabbits and hares (order Lagomorpha); and some are known as moles (order Insectivora). Many mammals that are harmful in certain areas under certain conditions actually may be of value in wild or uncultivated areas as game or as a source of food for predatory birds and fur-bearing animals.

SOME CHARACTERISTICS OF MAMMALS. The general characteristics of mammals are too well known to require detailed explanation in this text. Hair color in most small mammals tends to approximate the color of their usual background. The hair is shed annually or twice a year: in the fall and in the spring. Some mammals like the northern weasels and the snowshoe hares undergo a seasonal molt that makes them less conspicuous. Their brown summer hair is exchanged for a white coat late in the fall.

Mammals are far superior to invertebrates in intelligence, but this varies among species and among individuals in the same species. Some destructive mammals show little intelligence beyond the instinctive stage, whereas others such as the rat and fox possess great cunning and learn readily through experience.

REPRODUCTION IN MAMMALS. Nearly all mammals are viviparous—the young are brought forth in various stages of helplessness after the period of embryonic development known as the gestation period. These young are nourished on the mother's milk until they can forage for themselves. They are then said to be weaned. There is no distinct metamorphosis as in most insects. The young possess the organs of the adult and grow gradually to full maturity. The number of young or litters produced in a season is governed by the nature of the species and by the environment. Those forms that are heavily preyed upon by other species generally have a greater number of young than those forms that are relatively safe from enemies. Mammals may live and reproduce at intervals for a number of years, whereas insects die shortly after their one reproductive period is over.

The Rodents (Rodentia)

Rodents are generally small and possess clawed feet and in each jaw one pair of prominent and protruding, chisel-like teeth called incisors. The canine teeth are always absent. They may live on the ground, in the ground, in the trees, or partly in the water. Many species are active throughout the winter months, but some go into an inactive or torpid state, which is comparable to the hibernation of insects, for the whole winter period. Their body temperatures during this period may drop to nearly that of their surroundings, with respiration and pulse rate almost undetectable. It has been observed, however, that these rodents cannot survive a drop in body temperature as low as the freezing point.

With the exception of rats and mice most of the rodents have only one litter of one to several young each year in the spring. Tree squirrels and chipmunks may have two, and pocket gophers in the irrigated areas of the southwest may have as many as three litters. Many species of rats and mice are very prolific, but none can outdo the meadow mice with their 8 to 10 litters per year. The young of rodents, with some exceptions, are usually born blind, hairless, and helpless, but they develop rapidly. Porcupines are born fully haired, with open eyes, and are able to climb trees the second day after birth.

In addition to their damage to crops, many rodents may harbor deadly disease organisms that cause diseases such as tularemia, Rocky Mountain spotted fever, and bubonic plague.

Harmful rodents are divided into several groups. These are known as ground squirrels, tree squirrels, chipmunks, prairie dogs, and woodchucks (family Sciuridae); pocket gophers (family Geomyidae); porcupines (family Erethizontidae); and the rats and mice (families Heteromyidae, Cricetidae, and Muridae).

GROUND SQUIRRELS (Citellus spp.)

Description. Ground squirrels found in western North America are small mammals, the different species varying in length from 9 to 19 inches from nose to end of tail (Fig. 63). Their tails are generally short, with the exception of the California ground squirrels (Citellus beecheyi and subspecies), which have long, bushy tails similar to those of tree squirrels. The color of ground squirrels varies from gray to grayish-brown to reddish-brown in the different species and races, with the color brown predominating. All species have two thin membranous cheek pouches opening just inside the lips. These pouches are used to carry food for storage purposes.

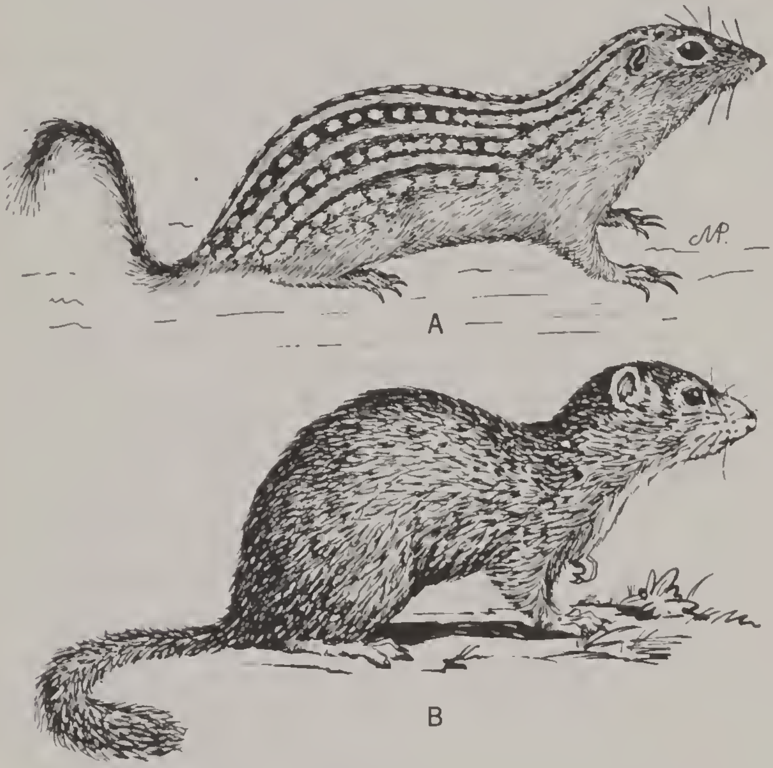


FIG. 63. A, Striped ground squirrel (Col. A. and M. Coll. Circ. 121-A); B, Franklin's ground squirrel (Iowa Agr. Expt. Sta. Bull. P43).

Food and Damage. Activity in ground squirrels is limited to the daylight hours. Their preferred food consists of seeds, especially the grains, which most species store below ground to be eaten during rainy days. Where these pests are allowed to go unchecked in cultivated areas losses to grains may amount to 25 per cent or more of the crop. Ground squirrels also feed on alfalfa, clover, and grasses, out of which they eat the joints. Wide swaths are commonly trampled around the edges of fields by the feeding squirrels. They dig up planted or sprouting seeds in the spring; this also causes crop losses. It has been estimated that 200 ground squirrels (Citellus beecheyi) on open range may eat as much as one steer or ten sheep. Most species, especially the striped ground squirrel (Citellus tridecemlineatus), also feed on insects, mice, bird eggs, and nestlings when they can find them.

Habitat. Ground squirrels live in burrows that they dig in the the soil of open, flat areas, hillsides, irrigation embankments, or rocky ledges. They use these burrows for shelter, food storage, and rearing of their young. These burrows may be solitary or "colonial" and vary in complexity, length, and depth (Fig. 64). Young ground squirrels generally dig short

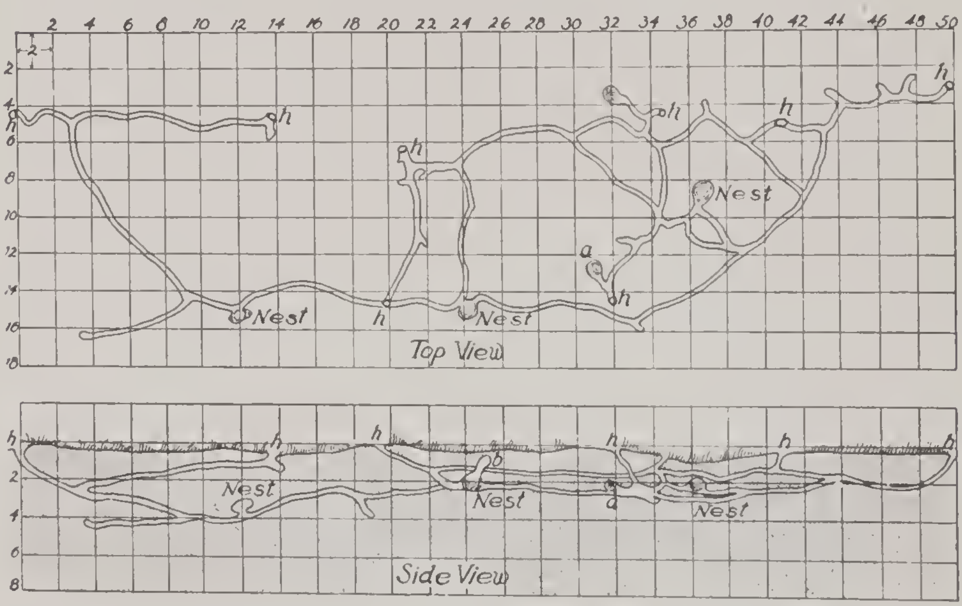


FIG. 64. California ground squirrel "colonial" burrow system. h, entrance; a, food store (from Storer, Calif. Agr. Ext. Service Circ. 79).

shallow tunnels. The solitary tunnels have only one entrance, but others may be dug nearly to the surface to serve as escape hatches in times of emergency or as exits after hibernation.

Life History. The annual life history of most species of ground squirrels is similar to that of the striped ground squirrel (Fig. 65). The Oregon and Columbian ground squirrels retire to their burrows as early as mid-August and go into a state of torpor that merges into the winter hibernation. The antelope ground squirrel remains semi-active all winter, feeding on stored food and coming out on sunny days.

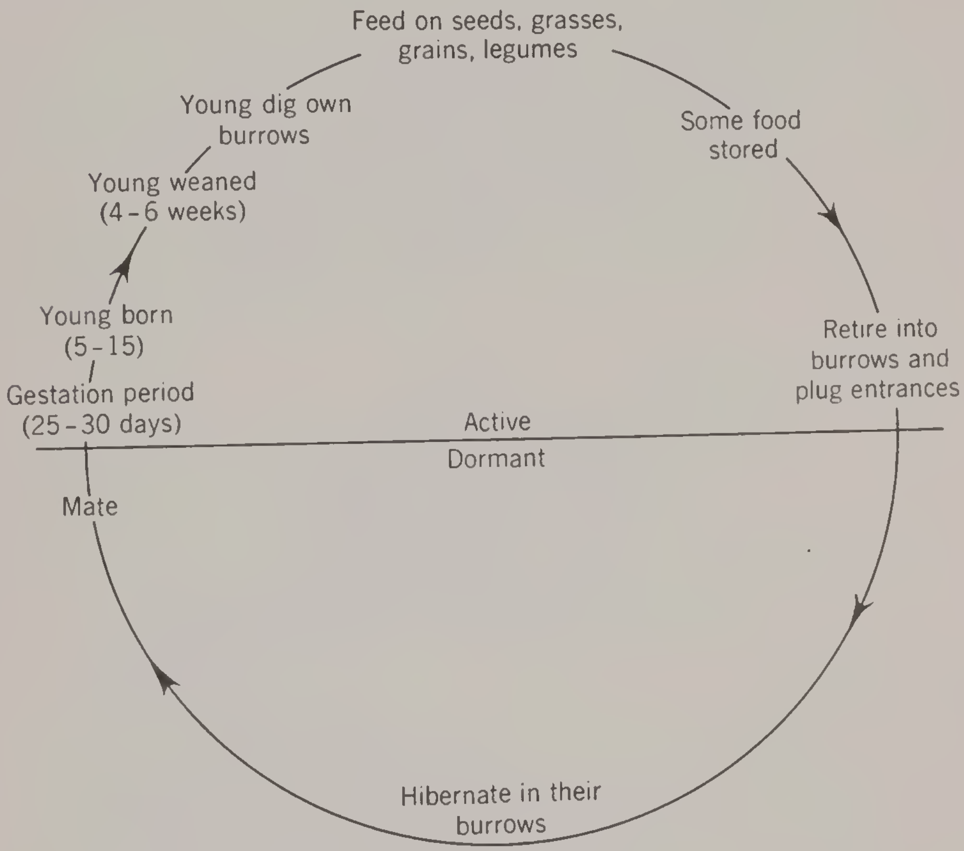

Feed on seeds, grasses, grains, legumes
Some food stored
Retire into burrows and plug entrances
Active
Dormant
Hibernate in their burrows
Mate
Gestation period (25-30 days)
Young born (5-15)
Young weaned (4-6 weeks)
Young dig own burrows

FIG. 65. Annual life history of the striped ground squirrel.

WOODCHUCKS OR GROUNDHOGS (Marmota spp.). There are only two species of woodchucks, the eastern woodchuck and the western woodchuck, with several subspecies, in the United States. Destroying them over limited areas is often essential to successful farming, but in non-agricultural areas they are actually useful mammals, because their burrows are used by many game and fur animals.

Description. The woodchuck is one of our largest rodents. It has a short, heavy body with a short, bushy tail and powerful legs developed for digging (Fig. 66). It is rather slow in its movements and does not go far from its burrow. Its fur is course, grizzled, and of a general greyish-brown color.

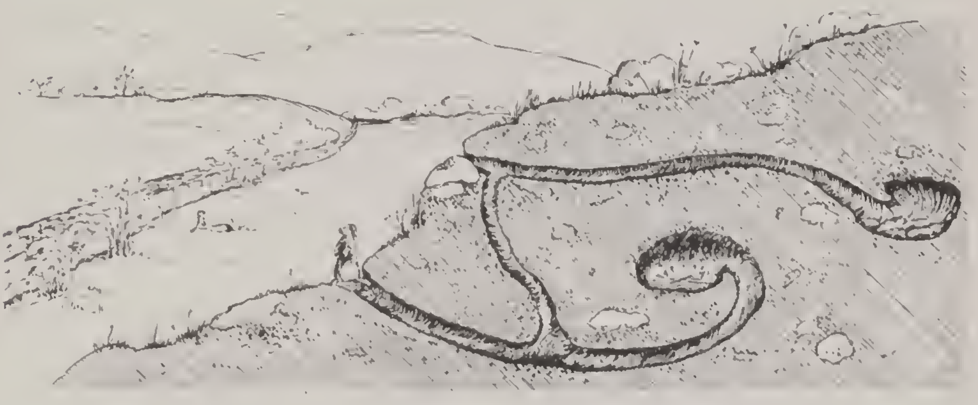


FIG. 66. A cross section through a hillside, showing a woodchuck and its den (redrawn from Hamilton, American Mammals, with modifications).

Food and Damage. On cultivated land both its food habits and burrowing habits are injurious. Woodchucks feed mainly on grasses, clover, alfalfa, and soybeans but often raid vegetable gardens. Both growing and shocked corn and the bark of young fruit trees may also be attacked. In addition to the forage consumed, the crops are reduced by trampling and by the large mounds made in the fields. Woodchuck burrows and mounds in hay fields are dangerous to horses and to field machinery. Trees may be injured by the burrows made under their bases.

Habitat. A woodchuck burrow is from 8 to 12 inches in diameter at its mouth but narrows down beyond its mouth (Fig. 66). It may consist of one or more branches with a nest at the end and one or more emergency exits, well hidden with no telltale soil around them.

Life History. See Fig. 67.

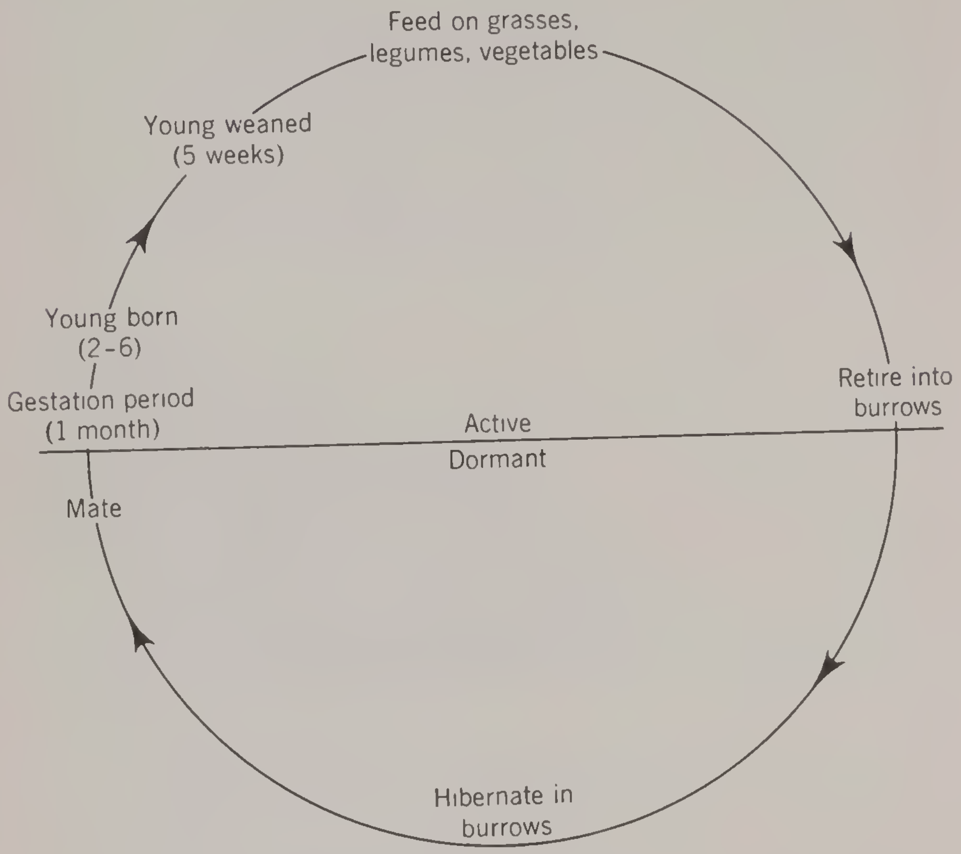


FIG. 67. Annual life history of the woodchuck.

POCKET GOPHERS (Geomyidae)

Range. Pocket gophers are found in every state west of the Mississippi and eastward in Illinois, Wisconsin, Indiana, and the Southeast. Locally they are known as salamanders, pocket rats, camas rats, or gophers.

Description. Pocket gophers are small-bodied rodents varying in length from 6 to 13 inches. Their fur color ranges from a light brown to a dark chocolate or black. Shades differ with species and subspecies. They all possess large, external cheek pouches lined with fine hair, for carrying food; conspicuous front incisors for burrowing and cutting food; small front feet with long, sharp digging claws; and a short, nearly naked tail (Fig. 68).

Food and Damage. Pocket gophers feed mainly underground, eating roots, tubers, bulbs, and stems of plants such as alfalfa, clover, vegetables, sweet potatoes, peanuts, and forage crops. They injure fruit trees by chewing up the roots and gnawing at the bark and palm trees by burrowing up the soft corners. Their mounds of earth smother vegetation and disfigure golf courses, lawn areas, and cemeteries. The work of pocket gophers is sometimes confused with that of moles, but an examination of Fig. 69 will readily reveal the difference. Their burrows, in addition, may cause breaks in irrigation canals, interfere with the distribution of irrigation water, and enhance soil erosion. One gopher may make a dozen mounds in a few days.

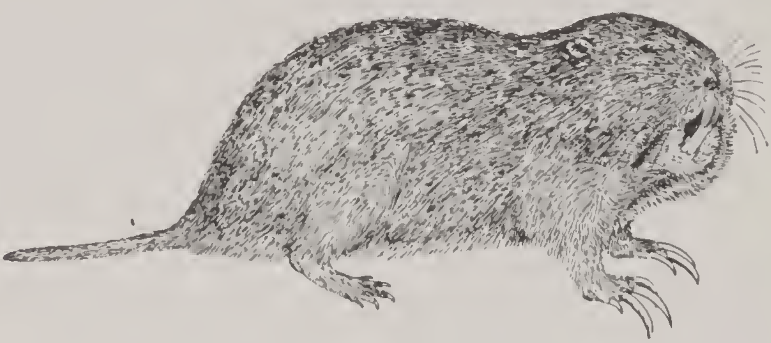


FIG. 68. A pocket gopher (from Col. A. and M. Coll. Circ. 121-A).

Habitat. Pocket gophers spend all their lives in underground burrows that vary in extent and depth (Fig. 70). One pocket gopher may cover an acre or more of ground with its tunnels and mounds that it makes by pushing out the earth at intervals through short lateral tunnels. These are kept plugged with soil. The mounds tend to be fan-shaped or one-sided because of the way the soil is pushed out. Their shape often gives a clue to the main tunnel location. Tunneling tends to be much closer to soil surface during the cooler months and much deeper during dry periods. Nests are located in the deeper tunnels.

Activity may not be apparent in dry, hot times of the year, since in digging the deeper tunnels the pocket gophers may place the excavated earth in higher-level tunnels. At such times poison baits may not be effective. There is usually only one gopher in a burrow system except during the breeding and rearing season. For purposes of feeding on surface vegetation, gophers make short, vertical laterals to the surface, later plugging them, with no mound on the outside.

Life History. See Fig. 71.

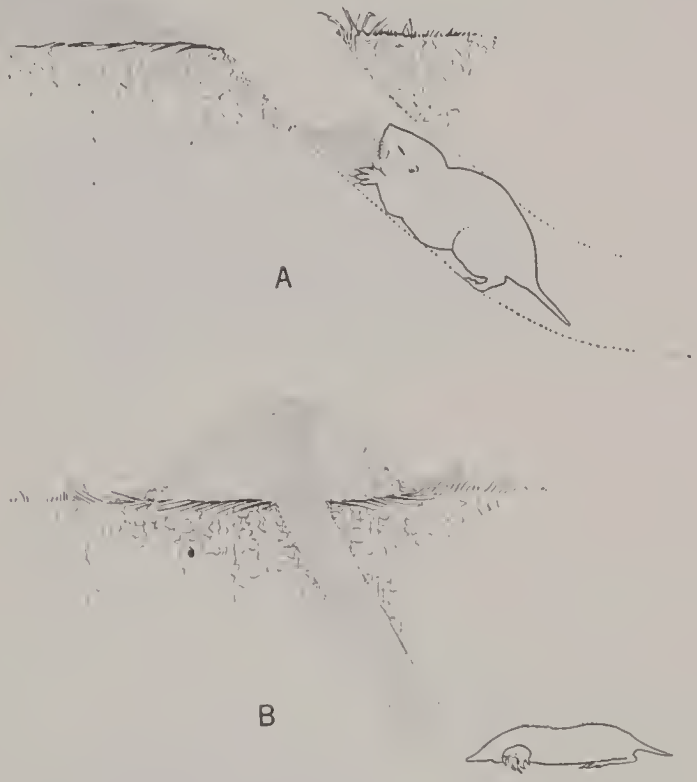


FIG. 69. Differences in mounds made by a pocket gopher and by a mole. A, mound of more or less fan-shaped pattern made by pocket gopher; B, volcano-like mound made by mole (from Storer, *Calif. Agr. Ext. Service Circ.* 79).

RATS. Rats and mice are undoubtedly the most numerous and also the worst mammal pests with which man has to contend. In numbers they greatly outstrip man, and they tend to be most abundant where foods are raised or stored in large quantities.

It has been estimated that one pair of brown rats and their progeny could theoretically produce a total of more than 350,000,000 rats in 3 years if three to six litters of nine to ten young were produced each year.

Many widely different species are classified as rats, and these are grouped into three families that also include our harmful mice. The Heteromyidae include the kangaroo rats and pocket mice; the Crecetidae include our native rats and mice such as the rice rat, the cotton rat, deer mice, and field mice; and the Muridae include foreign rats and mice such as the brown or Norway rat (Fig. 72) the black rat, and the house mouse.

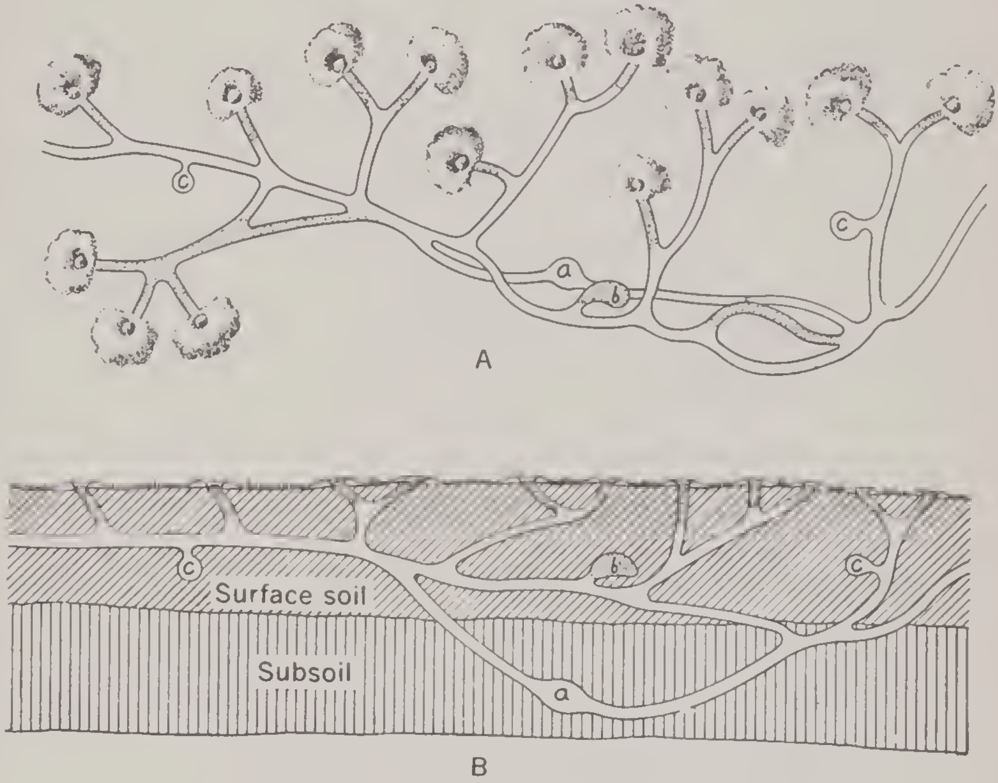


FIG. 70. Runway system of a pocket gopher. A, seen from above, shaded portions filled with excavated soil; B, vertical cross section; a, used nest filled with soil; c, storage chambers (from Crouch, U.S. Fish Wildlife Service Conservation Bull. 23).

Range. The kangaroo rats (Dipodomys spp.) are found in

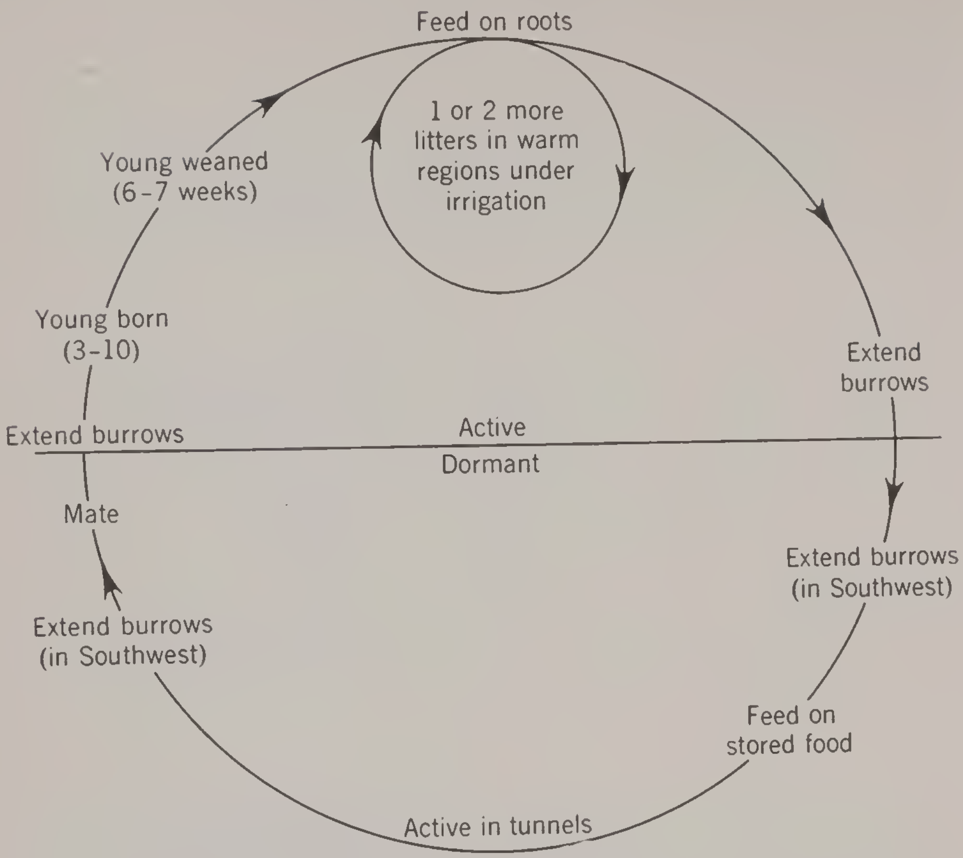


FIG. 71. Annual life history of the pocket gopher.

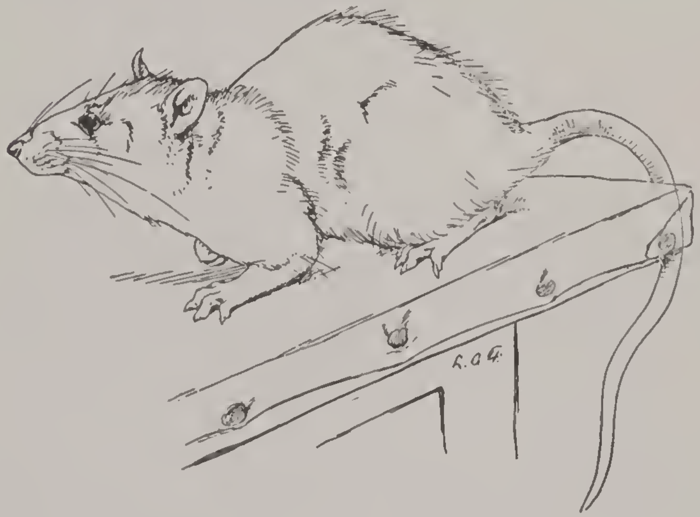


FIG. 72. The brown or Norway rat (courtesy of E. L. Palmer, copyrighted by Slingerland-Comstock Co.).

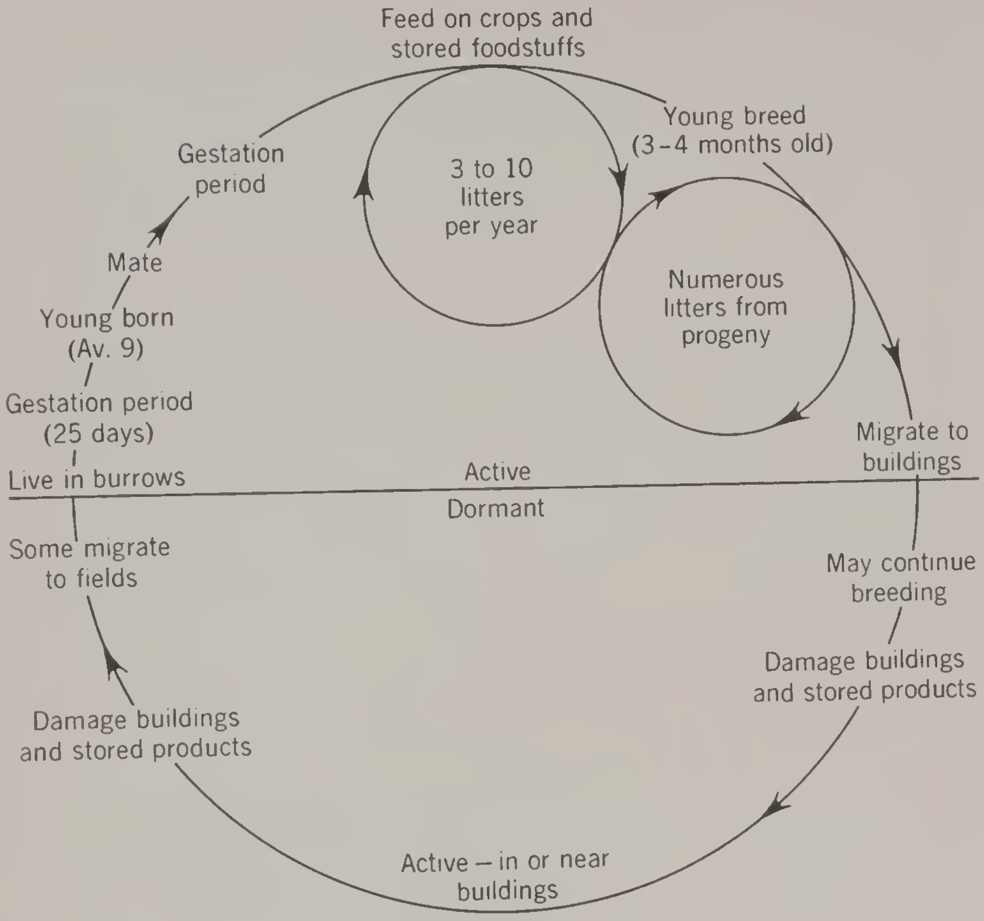
the semi-arid regions of the Far West, and the rice rat (*Oryzomys* spp.) in the tropics, Gulf states, and along the Atlantic coast to southern New Jersey. The cotton rat (*Sigmodon* spp.) ranges from southern Virginia to Florida and west in the southern states to southwestern California. The brown or Norway rat (*Rattus norvegicus*) is found everywhere in North America, but the black rat (*Rattus rattus*) is found only in the tropics, in the Gulf states, and in the west coast states.

Food and Damage. Rats will eat anything that humans eat and much more. The kangaroo rats feed chiefly on forage plants, and colonies of them near grain fields do considerable damage. All the rats mentioned above may destroy garden, field, fruit, and seed crops of all types. The brown and black rats, in addition, destroy or make uneatable huge amounts of stored food products; eat eggs, birds, poultry, and other small animals that are within their reach; damage buildings with their burrowing; and menace human health and lives with their disease-carrying potentialities. The kangaroo rats are noted for their large supplies of stored food, but none of the other rats store food to any extent.

Habitat. All rats found in the open generally live in burrows in the ground, but the brown and black rats may also live under floors or in the wall partitions of buildings. The kangaroo rats live in scattered colonies in burrows made under low mounds about 10 feet in diameter. The rice rat makes its nest on dry or wet ground under a tangle of weeds and brush or sometimes in a shallow burrow in the ground. The cotton rat may make its own shallow, twisting tunnel under logs and stumps or may use tunnels made by other animals. Like the rice rat, it may be found in dry or wet locations. Rats usually have well-defined trails leading from their burrows to their feeding grounds. The brown and black rats live gregariously in communities. They prefer to burrow under floors, lumber piles, and debris near buildings, but they may also burrow in ditch banks, open fields, or salt marshes. The burrows are short, shallow shafts rarely over 1 1/2 feet deep.

Life History. See Fig. 73 for annual life cycle of the brown rat.

MICE OR VOLES. Mice are closely related to rats. The numerous species and subspecies belong to the same families



Feed on crops and stored foodstuffs
Young breed (3-4 months old)
3 to 10 litters per year
Gestation period
Mate
Young born (Av. 9)
Gestation period (25 days)
Live in burrows
Numerous litters from progeny
Migrate to buildings
Active
Dormant
Some migrate to fields
May continue breeding
Damage buildings and stored products
Damage buildings and stored products
Active – in or near buildings

FIG. 73. Annual life history of the brown rat.

as the rats. They also have many of the same bad habits and characteristics of rats and should be reduced or eradicated in cultivated areas.

The mice may be divided into two groups on the basis of their tail length. The short-tailed group consists of the meadow or field mice (Microtus spp.), the pine mice (Pitmys spp.), and the lemming mice (Synaptomys spp.). The long-tailed group is made up of the deer or white footed mice (Peromyscus spp.), the pocket mice (Perognathus spp.), and the common house mice (Mus spp.)

Range. The meadow mice are widely distributed throughout the United States. The pine mice are found only east of Kansas and Nebraska. The range of the lemming mice includes the northeastern quarter of the United States and eastern Canada west to a large area extending from California to western Alaska. The white footed and house mice may be found all over North America except in the extreme north. The pocket mice are found in the dry and semi-arid plains west of the Mississippi River.

Description. Mice are much smaller than rats. The pine mouse is smaller and finer furred than the meadow mouse (Fig. 74). The tail of the meadow mouse is nearly twice as long as its hind foot (measuring from hock to tip of toes); the tail of the pine mouse is slightly longer than its hind foot; and the tail of the lemming mouse is no longer than its hind foot (Fig. 75). White footed mice have well-haired tails in contrast to the hairless or sparsely haired tails of the other mice. Pocket mice have long hind legs and external fur-lined pouches, like the kangaroo rats and pocket gophers.

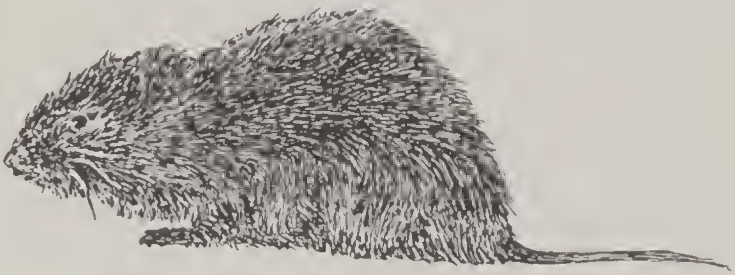
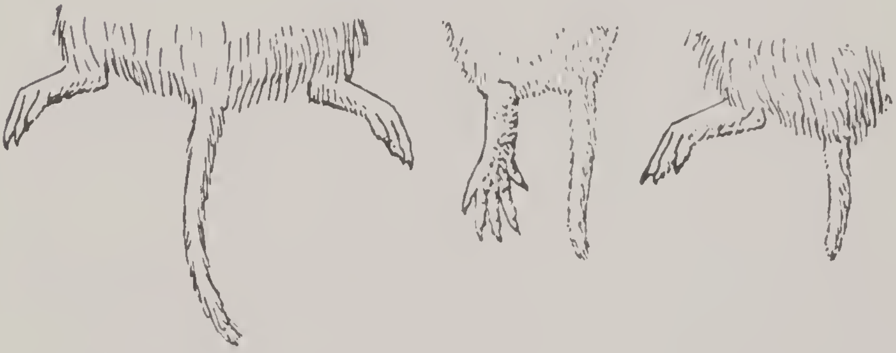


FIG. 74. The meadow mouse.



Meadow mouse Pine mouse Lemming mouse

FIG. 75. The tail lengths of three common injurious mice (from *Univ. of Ill. Coll. Agr. Circ.* 634).

Food and Damage. Mice, like rats, tend to be omnivorous, but generally they feed on vegetable matter such as seeds, berries, and succulent plant parts. Meadow, lemming, and pine mice may destroy thousands of fruit and timber trees annually during the winter by gnawing the bark from the base of the trees or from their roots. The meadow and lemming mice usually confine their feeding to the bark at the ground surface, whereas the pine mice attack the bark of the roots as well. The white footed mice may feed on conifer seeds in logged-over areas and hinder reforestation. When abundant, pocket mice destroy much grain and range forage. House mice, in addition to destroying or damaging stored foods, may also become very abundant in fields and destroy grain and growing crops.

Habitat. The pine mice spend most of their lives underground in a maze of tunnels made for protection, breeding, and feeding purposes. These pine mice burrows have small openings about 1 inch in diameter located near the bases of trees or under any type of growth that the mice may feed on. Meadow, lemming, deer, and house mice make nests in short, simple burrows in the ground, among the roots of shrubs and trees, in decayed stumps, in hollow trees, and under logs. Deer mice may also make their nests in abandoned bird nests on the ground and in shrubbery.

Mice have surface trails under rank growth, mulch, and weeds. These are clearly visible when the growth is parted or lifted up. Deer mice do not make runways of their own but may use those made by other mice. Mice may also make use of the tunnels of moles and pocket gophers.

Most mice tend to colonize, but pocket mice live singly in individual burrows. The mounds outside these burrows resemble those of pocket gophers and are plugged during the day, but the core plugs are smaller, and mouse tracks and tail marks are evident on the mounds.

Life History. Mice are cyclic animals and may appear in great numbers in some years without warning. Pocket mice usually produce only two litters per year in northern areas, but other groups of mice usually produce several litters. Meadow mice, like brown rats, may mate again right after the birth of the young. See Fig. 76 for the annual life history of the meadow mouse.

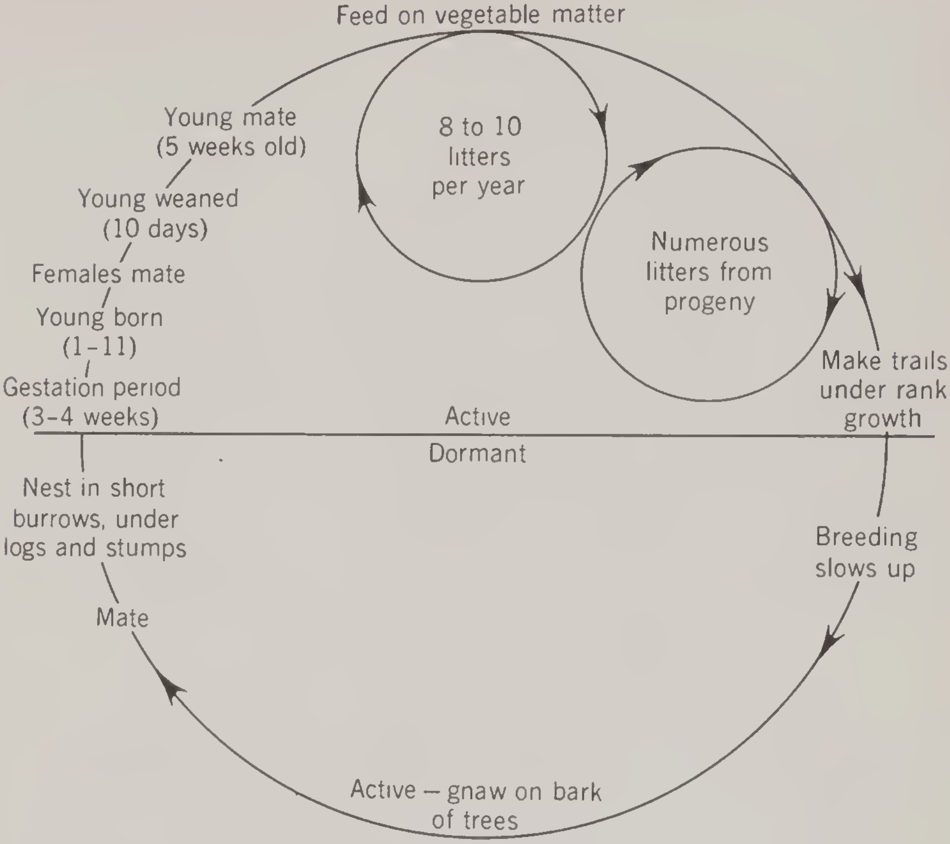

Feed on vegetable matter
8 to 10 litters per year
Numerous litters from progeny
Young mate (5 weeks old)
Young weaned (10 days)
Females mate
Young born (1-11)
Gestation period (3-4 weeks)
Active
Dormant
Make trails under rank growth
Nest in short burrows, under logs and stumps
Breeding slows up
Mate
Active – gnaw on bark of trees

FIG. 76. Annual life history of the meadow mouse.

TABLE 22

SOME ADDITIONAL RODENTS AND THEIR DAMAGE

Name	Range	Damage
Prairie dogs (*Cynomys spp.*)	Western North America but east of the Rocky Mts.	Feed on stems and roots of forage grasses, grains and alfalfa
Porcupines (*Erethizon spp.*)	Northern U. S. into Canada and in mountains of Southwest	Feed on inner bark of conifers; girdle trees; may completely consume coniferous seedlings

Table 22 (Continued)

Name	Range	Damage
Red squirrels (Tamiasciurus spp. and subspp.)	Most of forested North America	Feed on and store nuts, berries, and seeds; also feed on fruits and buds of trees; may interfere with reforestation
Fox and gray squirrels (Sciurus spp. and subspp.)	Most of forested North America	Same as red squirrels
Chipmunks (Tamias and Eutamias spp. and subspp.)	Wooded areas of North America	Feed on grains, nuts, bulbs, planted seeds; may interfere with reforestation

Rabbits and Hares (Lagomorpha)

Rabbits and hares are not classed as rodents, but they behave similarly. They are considered game animals, so a closed season is in effect on them in many parts of the United States. Although they are capable of much serious damage to crops in cultivated areas, they should be reduced in numbers only to insure comparative safety to crops. They may be a potential danger to human health in some areas by carrying the organisms of Rocky Mountain spotted fever or tularemia.

Range. The true rabbits or cottontail rabbits (Sylvilagus spp.) are found as various subspecies throughout the United States and Canada, and the jack rabbits (Lepus spp.) are found west of the Mississippi in the United States and in Canada and Alaska. The snowshoe rabbits or varying hares (Lepus spp.) range throughout northern United States and are found in the East as far south as the Virginia mountains.

Description. Rabbits (Fig. 77) and hares are characterized by their large ears, bob tails, and, long muscular hind legs used in propelling them at great speeds from their enemies. The hind feet of varying hares are large and broad and heavily furred between the toes, giving them the name of

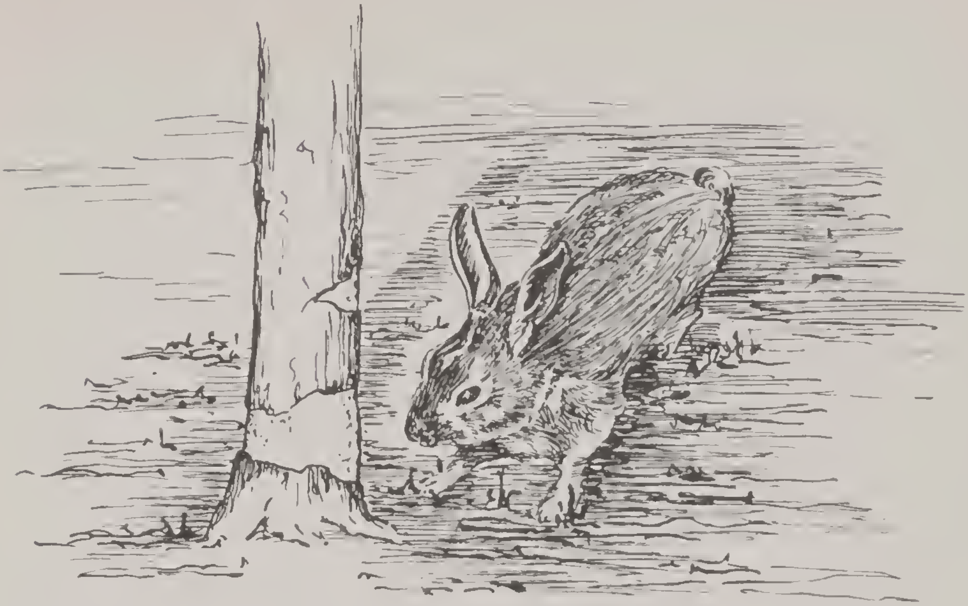


FIG. 77. Cottontail rabbit and injury to a young tree.

snowshoe rabbits. Jack rabbits are large hares with very long ears and long, powerful hind legs.

Food and Damage. Rabbits and hares are chiefly vegetarian, feeding on succulent vegetation in the summer and on twigs, buds, and bark of various trees including orchard trees and conifers in the winter. They are especially fond of the bark of apple trees, and in years of abundance or when snow is deep they may do serious damage to fruit trees in orchards and nurseries (Fig. 77). In some areas rabbits may limit natural reforestation by destroying tree seedlings. The black tailed jack rabbits in the Northwest may destroy entire fields of growing crops in a single night when they move in bands from sagebrush areas. In some regions rabbit and hare populations fluctuate in cycles of 5 to 10 years. It is during the peaks of their cycles that the greatest damage may be done to crops.

Habitat and Activity. Rabbits and hares do not live in family groups but tend to be solitary. Cottontails and varying hares may take shelter in old burrows made by other animals, under brush piles, in thickets, in hollow logs, and in stone walls. Home to most rabbits and hares is a small depression made by the weight of their body in the ground or in plant litter. This resting place is called a form. Forms may be in the open or under protecting cover. Generally they are located so that the rabbit or hare may watch its surroundings for enemies. A rabbit may have more than one form in its range but generally uses one much more than the others. Jack rabbits live in open places and also have forms but rely mainly on their great speed to escape from enemies. Hares and rabbits are active mainly at dusk or at night, resting in their forms during the day. Both hares and rabbits make use of regular trails but do not keep to them in looking for food.

Cottontails and most jack rabbits make nests for their young either in open hay fields or at times in stone walls and in brush piles. The nest is merely a shallow hole or depression in the ground, lined with grass and with fur from the mother. Varying hares make no nests but use their forms as nests.

Life History. See Fig. 78 for the annual life history of the cottontail rabbit. Varying hares and jack rabbits produce two

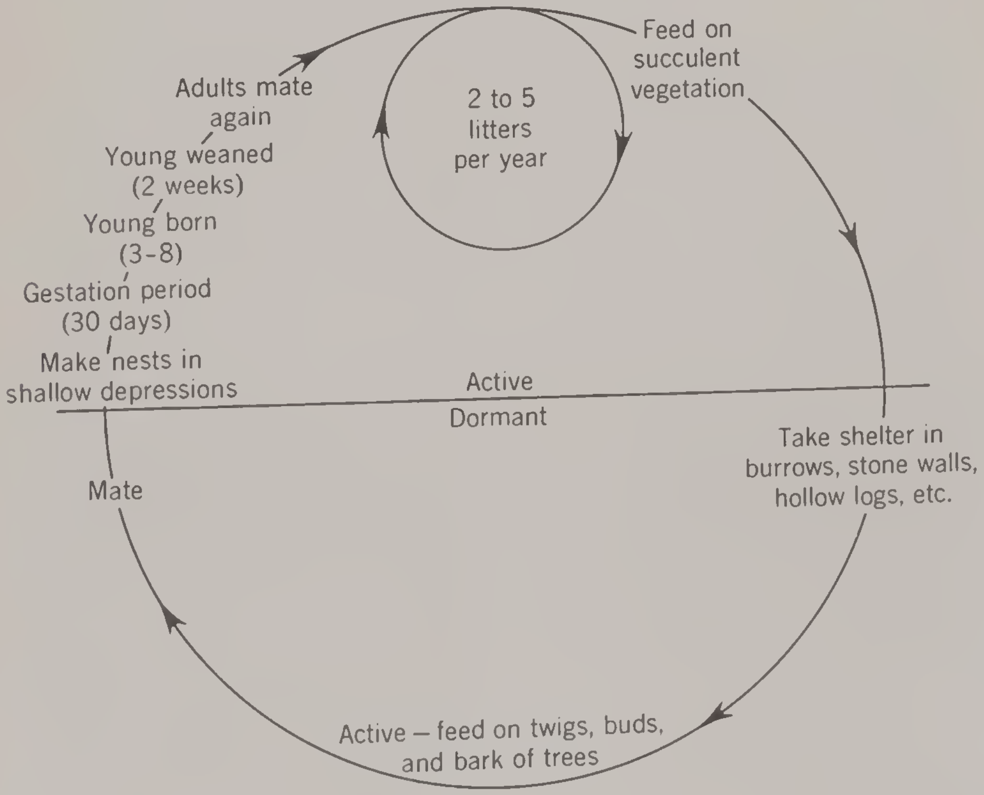

Feed on succulent vegetation
2 to 5 litters per year
Adults mate again
Young weaned (2 weeks)
Young born (3-8)
Gestation period (30 days)
Make nests in shallow depressions
Active
Dormant
Take shelter in burrows, stone walls, hollow logs, etc.
Mate
Active — feed on twigs, buds, and bark of trees

FIG. 78. Annual life history of the cottontail rabbit.

and sometimes three to four litters per year and average three to four young per litter. The young of hares but not those of rabbits are born fully furred and with their eyes open. They are able to get about within a day after birth and are weaned within 2 to 4 weeks.

Moles (Insectivora—Talpidae)

Moles are not found in arid regions but are abundant in moist, rich soils that abound in earthworms and insect larvae. Several species are found in North America.

Description. Moles have an elongated body, a pointed snout, and a short tail (Fig. 79). Their front limbs are short and stout with strong claws and palms turned outward. Their fur is soft, short, and velvety, varying from gray-brown to black in the different species. Their eyes and ears are minute; the common eastern mole and western moles are almost blind. They are larger than mice and differ from pocket gophers, which have a rounded nose and evident eyes and ears.

Food and Damage. The main food of moles consists of adult insects, insect larvae, and earthworms that wander into their tunnels. Eastern moles may eat some vegetable

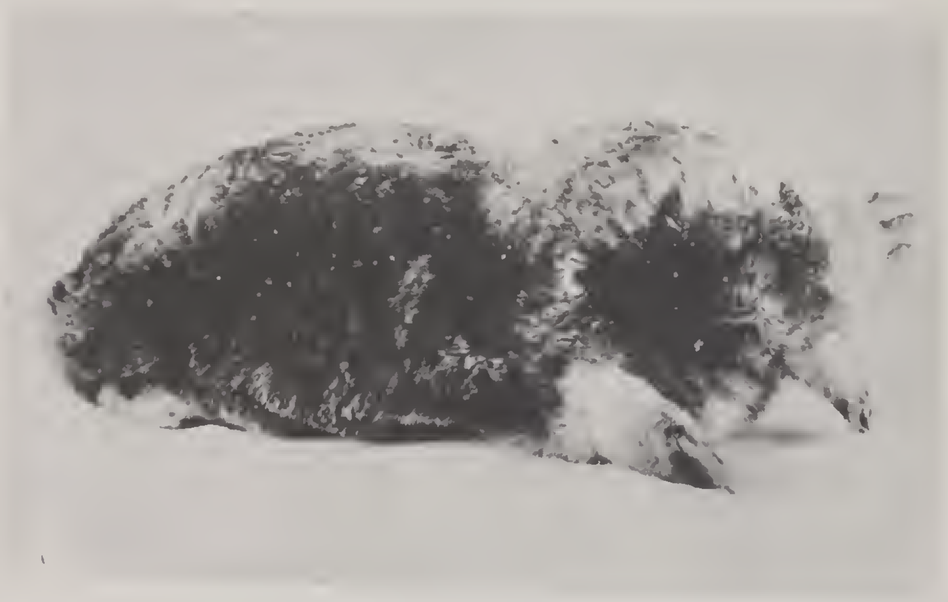


FIG. 79. The common eastern mole.

matter, but mice are probably responsible for much of the root, tuber, and bulb damage attributed to them. Townsend's mole in the Pacific Northwest may feed on bulbs, root crops, peas, beans, vetch, oats, corn, and wheat. It shreds large tubers and bulbs with its claws and works the shreds into its mouth. Damaged roots are mangled, not cut clean.

In tunneling through the soil in search of food moles make telltale ridges and may push out mounds of soil (Fig. 69). This work disfigures lawns and golf courses, ruins seedbeds in gardens and nurseries, and heaves up and injures the roots of young vegetable crops. Their mounds in hayfields dull the knives of the cutter bar. Mole runways may be used by mice, pocket gophers, and rats as convenient highways for marauding activities.

Habitat. Moles live underground but may occasionally venture out of their tunnels at night. In making their runways they leave ridges and conspicuous mounds of earth. Mounds indicate deep tunneling and may be mistaken for pocket gopher mounds in areas where these are present (Fig. 69). The burrows are simply a labyrinth of runways. The deeper runways may have an enlargement for a nest. Moles, except the star nosed and hairy tailed ones, tend to be solitary, and usually only one is found in a runway system.

Moles have the habit of repairing openings in used runways or in places where they have been stamped down. This makes easy the determination of active runways for the purposes of trapping. Surface runways may be used only once, or they may be used as main highways.

Life History. See Fig. 80 for the annual life history of the common eastern mole.

BIRDS AND AGRICULTURE

There are very few wholly injurious birds as far as their relation to agriculture is concerned. Most birds are highly beneficial, their diet consisting of such items as insects, weed seeds, and wild berries.

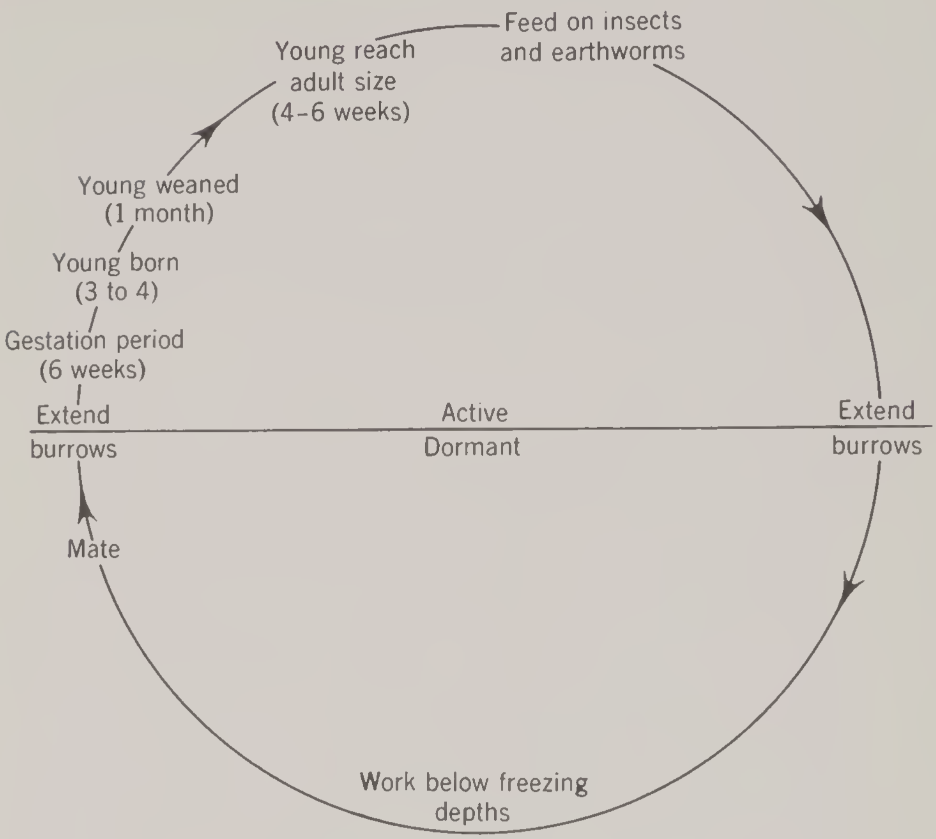

Feed on insects and earthworms
Young reach adult size (4-6 weeks)
Young weaned (1 month)
Young born (3 to 4)
Gestation period (6 weeks)
Extend burrows
Active
Dormant
Extend burrows
Mate
Work below freezing depths

FIG. 80. Annual life history of the common eastern mole.

Occasionally, when the food requirements of birds become grains, fruits, vegetables, or poultry, their activities clash with agriculture. Damage may occur in local areas in some seasons of the year, or it may be widespread under the stress of unusual climatic conditions that destroy their natural food supplies. At such times control measures are usually in order, since any good characteristics the birds may have are overbalanced by their immediate destructiveness.

GENERAL CHARACTERISTICS OF BIRDS. It is beyond the scope of this book to consider the structure of birds in any detail The names and location of the external parts useful in their identification is illustrated in Fig. 81.

Breeding takes place mainly in the spring. Eggs are usually deposited in nests (Fig. 82). These nests may be made of materials such as sticks, twigs, rootlets, grass, straw, and sometimes mud as a cement, and may be lined with softer material such as feathers or hair. Nests are built either on the ground or at varying heights from the ground in bushes and trees. Just where a nest is built depends on the bird species or on the environment.

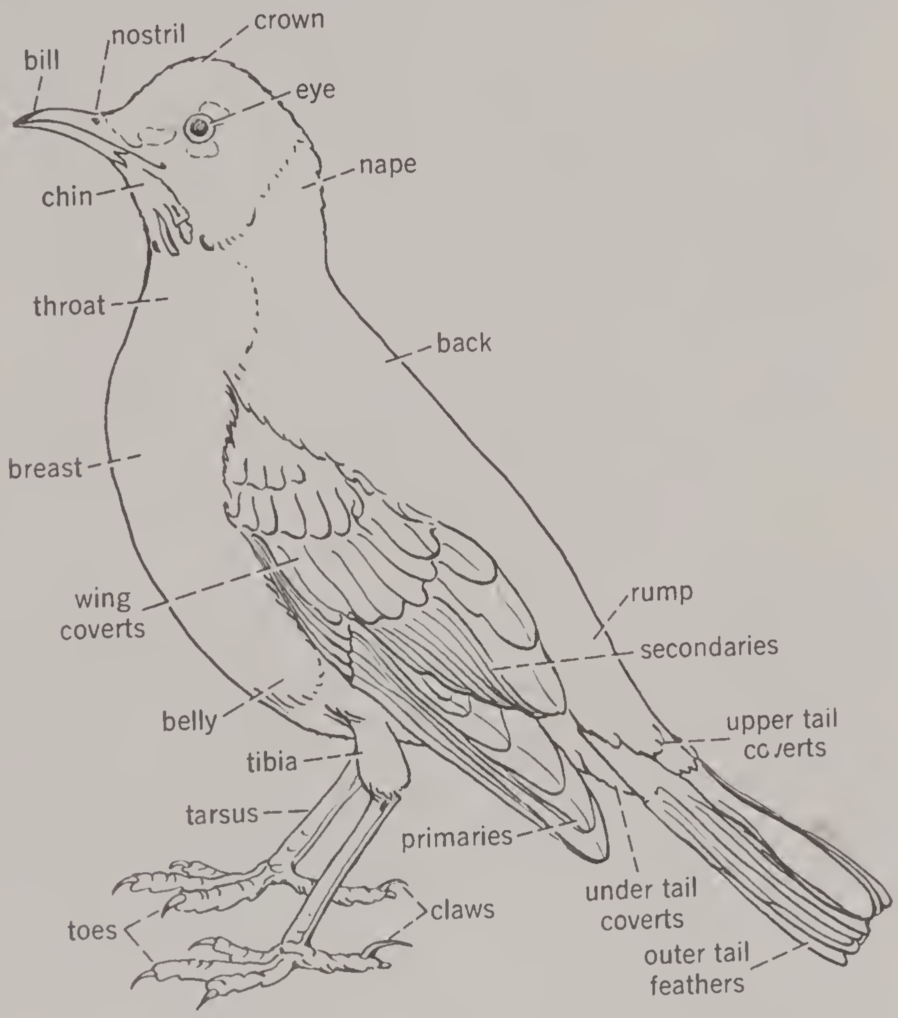


FIG. 81. Parts of a bird (robin) used in identification.

Unlike those of insects, birds' eggs require incubation for a definite period at the body temperature of the parents for development and hatching to take place. The eggs may be evenly colored or may be spotted or mottled with other colors according to the species.

Young birds (nestlings) may be naked and helpless like those of arboreal birds, or they may be covered with down and active, and self-feeding like those of birds such as ducks, geese, pheasants, partridges, and grouse. Nestlings develop rapidly and they are generally on their own and able to fly in about 3 or 4 weeks. One or more broods may be

FIG. 82. A robin's nest in a tree.

reared in a season. This is determined by the species and by the food supply.

Birds are not able to hibernate in cold climates. They either fly to warmer regions, often thousands of miles away, in the fall, or overwinter as best they can in the colder regions. Molting takes place once or twice a year—in the late summer when all feathers are replaced, and sometimes in late winter or early spring when only a variable part of the body plumage is changed. Because of molts, sex, or age, birds may not look alike the year around. Males may differ from females of the same species, and young birds may differ from their parents. The plumage of females is generally duller than that of the males.

Most birds roost at night in trees and bushes, but a few like the owls, nighthawks, and whip-poor-wills roost during the daytime and are active only at night. Through necessity, birds are wary creatures or soon become so when disturbed or shot at often. Some of our birds have adapted themselves well to a changing environment brought on by depletion of natural wild areas and extensive agriculture; whereas others are on the decrease and may some day become extinct. The birds that are on the increase are generally those that tend to be gregarious and band together in flocks, sometimes of enormous size, during the summer, fall, and winter. These are the ones most often responsible for crop damage, which warrants their reduction in numbers. These flocks may use definite trees for their nightly roosts. Control measures directed at these roosts may simplify population limitation.

The Crow Family (Corvidae)

The family Corvidae includes the crows, ravens, magpies, and jays. Some of these may at times be destructive to crops and to the eggs and young of birds, whereas at other times they may be beneficial and feed largely on insects, small rodents, and weed seeds. All are omnivorous in their feeding habits and band together in flocks of varying size during the summer, fall, and winter.

THE COMMON CROW (Corvus brachyrhynchos)

Range. This crow in its various subspecies ranges practically over all the United States, but it is most important in relation to agriculture in the Atlantic coast states as far south as North Carolina, in the central and upper Mississippi Valley, and in Kansas, central Oklahoma, and north central Texas in the winter.

Identification. The crow is jet black and averages 19 inches from tip of bill to end of tail (Fig. 83). Its deep, sturdy wingbeat distinguishes it in flight. Nearly everyone is familiar with the loud ca-ah, ca-ah, ca-ah of the crows.

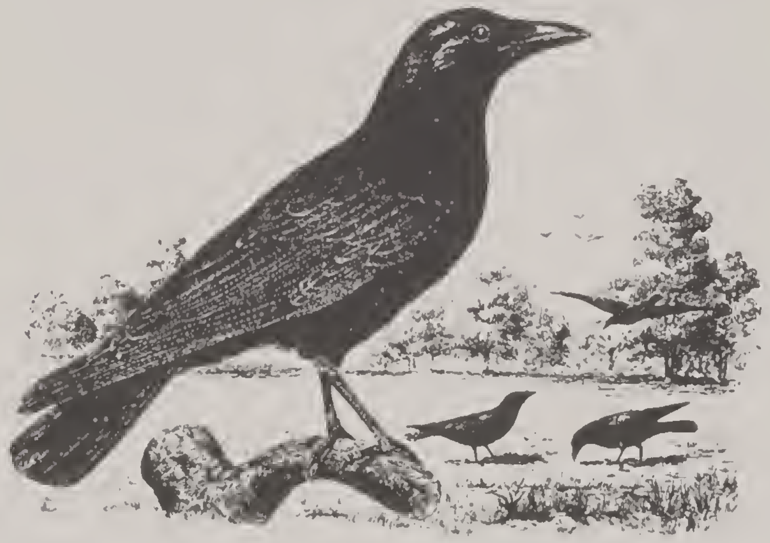


FIG. 83. The crow (from U.S. Fish Wildlife Service Conservation Bull. 15).

Food Habits. Crows have voracious appetites. About 28 per cent of the yearly food of the adult crow consists of insects, crustaceans, snails, reptiles, amphibians, wild birds and their eggs, poultry, small mammals, and carrion. Nestling birds in particular consume large numbers of insects that are fed them by their parents. Nearly 72 per cent of the adult crows' annual food is vegetable matter, and of that more than half consists of corn. Crows may injure corn by digging up the seed, pulling up the sprouted corn, or feeding on corn ears in the ripening and ripened stages. Crows will feed on other ripened grains such as wheat, oats, sorghums, buckwheat, and fruit and vegetables when corn is not available. Late-maturing grains are sure to be damaged in the vicinity of large roosts.

Life History. Crows may winter and breed both in the south and in the more northerly regions, but in either case the breeding ground is north of the wintering area, sometimes as much as 1000 to 1500 miles away in Canada. See Fig. 84 for annual life history.

THE WHITE NECKED RAVEN (C. cryptoleucus). This bird, found in southwestern United States, has habits similar to those of the crow but may be distinguished by its slightly larger size, coarser and longer beak, deep gutteral croaks, and a tendency to soar with the tips of its primaries separated and upturned.

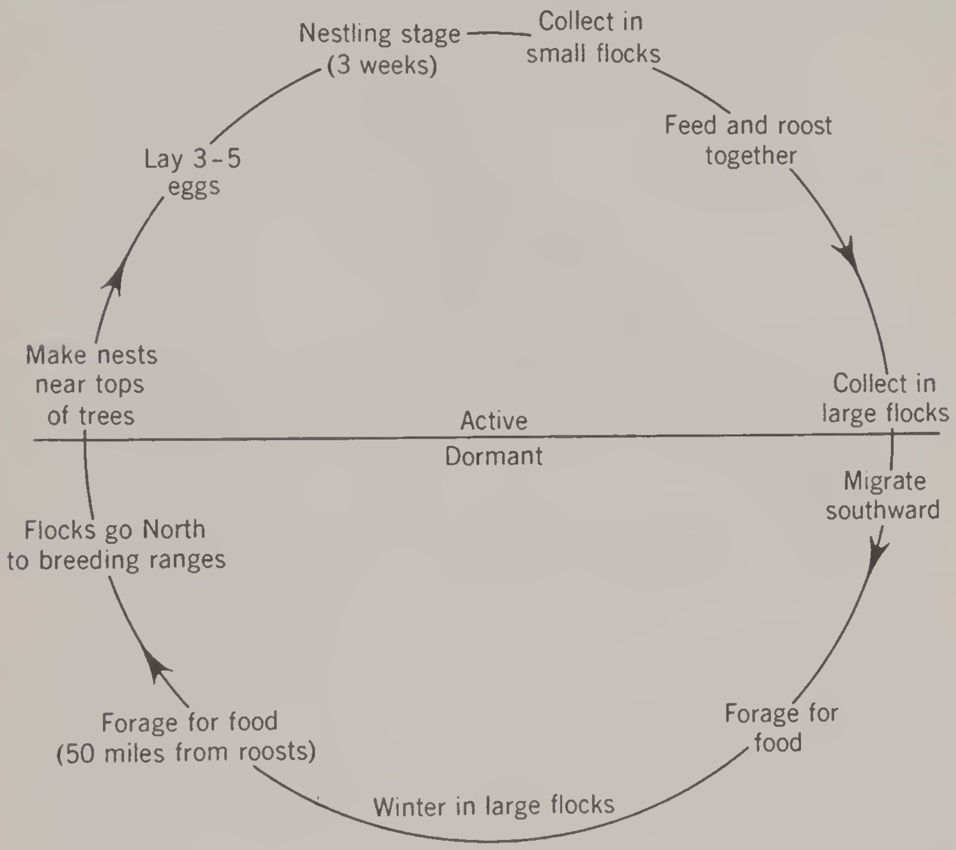


FIG. 84. Annual life history of the crow.

THE MAGPIES AND JAYS. The noisy magpies and the jays are much smaller birds than the crows and ravens but have similar habits. The magpie (Pica pica) has a black-and-white-marked back and wings and a long tail, which differentiate it easily from other birds. The magpie is an inhabitant of the plains and Rocky Mountain regions but may wander as far east as Illinois in the winter.

The jays, which include the blue jay, Canada jay, and Steller's jay, average about 11 1/2 inches in length. Their bright blue markings (except those of the Canada jay which are a fluffy gray in color) easily distinguish them from other birds. Jays tend to move southward in the winter but some remain in their usual range throughout the year. One or another species of jay is found throughout the United States and Canada. The most common of the three, the blue jay (Cyanocitta cristata), is found only east of the Great Plains.

Both jays and magpies are found in flocks during most of the year and may be injurious to grains, fruits, and nestlings in the summer. They also feed on small mammals, birds' eggs, and insects.

The Blackbirds (Icteridae)

The blackbirds, in addition to those so called, include birds such as the bobolink, the orioles, the grackles, and the cowbirds.

Description. Although the name implies it, some species are not strictly black. Some are buff, and others show metallic blue and green or red or yellow areas on their body and wings. Except for the grackles, which average from 12 to 16 inches in total length, the blackbirds range from 7 1/4 to 10 inches in length (Fig. 85). Most species are characterized by their harsh whistles, chatters, and croaks.

Habits. The members of this family generally prefer swamps, wooded areas along streams, coastal lowlands, and tidal marshes as habitats. Except during the breeding season they all tend to congregate in flocks and rove about the country, rarely returning to the same feeding grounds daily. Often the flocks are mixed, with more than one species of blackbird in them. The nests are above the ground in trees, bushes, or cane-like reeds. The bobolink nests on the ground in fields. Blackbirds usually rear one brood per year. The cowbirds do not build their own nests or incubate their own eggs. They simply lay their eggs in the nests of other birds and let the foster parents incubate them and feed their young. Some species such as the bobolink and the Baltimore oriole migrate to South American countries for the winter, whereas other species such as cowbirds, grackles, and blackbirds move varying distances south of their summer range.

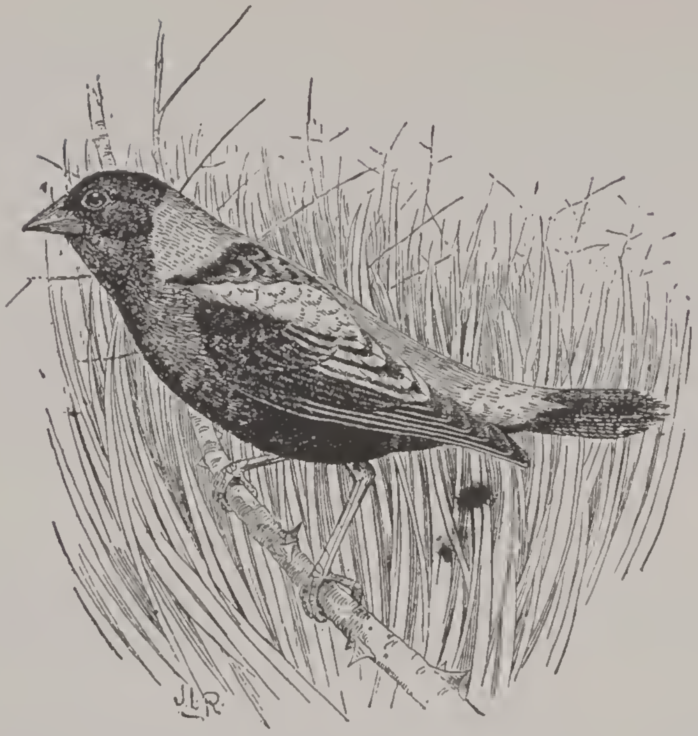


FIG. 85. Bobolink (from U.S. Dept. Agr. Farmers' Bull. 65).

Food and Destructiveness. Members of this family may be most destructive in the late summer and fall when their large flocks swoop down on unharvested grain fields. They feed on rice, corn, wheat, oats, and other grains in the sprouting, milk, and ripened stages. Some species such as orioles may attack fruits such as cherries and blueberries and do considerable damage in small plantings. Some blackbirds occasionally rob nests of other birds and devour the eggs or nestlings. Insects also comprise a large part of their diet and from that standpoint the blackbirds may do as much good as harm. Reduction of their numbers is justified, however, when large flocks descend in any grain-growing region.

The Starlings (Sturnidae)

These chunky, short-tailed black birds were imported about 1890 and have found conditions so favorable that they are now found over most of the United States. Their length averages 8 1/2 inches. They have a long, pointed bill, pointed wings, dark, metallic-green feathers, with the body feathers tipped with white or buff. This flecked appearance is most conspicuous in the fresh fall plumage.

Starlings nest in tree cavities or in crannies on buildings, cliffs, or rocks. In the winter they roost about buildings in towns and cities. Some flocks migrate south. Their nests contain four or five pale-blue eggs, and there may be up to three broods per season. Except when mating these birds are gregarious and often associate in flocks with red-winged and rusty blackbirds, cowbirds, and grackles. Their food habits are similar to those of the blackbirds, but in addition they tend to drive beneficial birds from their range.

The Grosbeaks, Sparrows, and Finches (Fringillidae)

The Fringillidae are a large family of birds including nearly 100 species in the United States. They are generally beneficial and feed on weed seeds and insects. Some species may at times be harmful to fruits and grains, and a few species are objectionable because of nesting in crannies in buildings and on vines growing on building walls. They travel in mixed flocks, some species migrating southward in the winter and others wintering near their breeding grounds.

The English sparrow (family Ploceidae), which has spread over most of the United States since its introduction in 1850, is particularly troublesome in the above respects and in addition drives many beneficial birds from its territory (Fig. 86). Its bad habits overshadow the little good it does in feeding on some insects.

Horned Larks (Alaudidae)

The horned larks (Erimophila alpestris and subspecies) are small, hardy birds with yellow or white throats, black marks across the breast, and small, pointed tufts of dark feathers behind the eyes, which give them a horned appearance (Fig. 87). They have the habit of walking instead of hopping and when they are seen in flight the black tail contrasts sharply with the white underparts.

They range over most of the United States in the open country and are particularly fond of deserts, prairies, and fallow fields. They nest early, even before the snow is off the ground, in the open on bare ground in a depression or near a stone or clod. The eggs are thickly and finely speckled with brown.

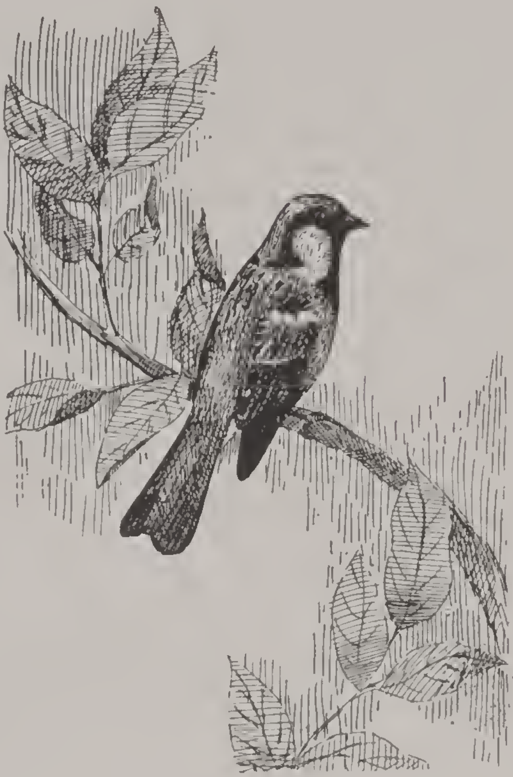


FIG. 86. English sparrow (from N. C. Agr. Ext. Service Ext. Circ. 170).

Horned larks form flocks in the summer, fall, and winter, often numbering in the thousands. Vegetable matter such as seeds and grains form the main part of their food, but nestlings are fed mainly on insects which are also about 20 per cent of the adults' diet.

The horned larks of California are almost entirely vegetarian. They winter in great numbers on the valley floors, but most migrate into the foothills, dry grasslands, and desert for the breeding and nesting season. During May and June the young of the resident larks may be noted in the fields, but beginning in early July there is a sudden great increase in population due to the migration from open country into the farming districts. This increase continues into the early fall as additional flocks immigrate.

Weed seeds and grains form a large part of their diet, but the birds have developed a liking for succulent vegetable crops, which results in severe damage in the irrigated valleys and dry-farmed areas during the dry season from mid-June to November. Damage may start when the plants break through the soil, and it continues with the growth of the crops. Whole fields as large as 200 acres may be destroyed. Seedlings are pulled up or nipped off, foliage is pecked, and bean and pea blossoms are eaten. The crops damaged are lettuce, carrots, beets, spinach, turnips, beans, and peas. Damage generally starts in a small area in the middle of a field and spreads outward to its edges with continued feeding.

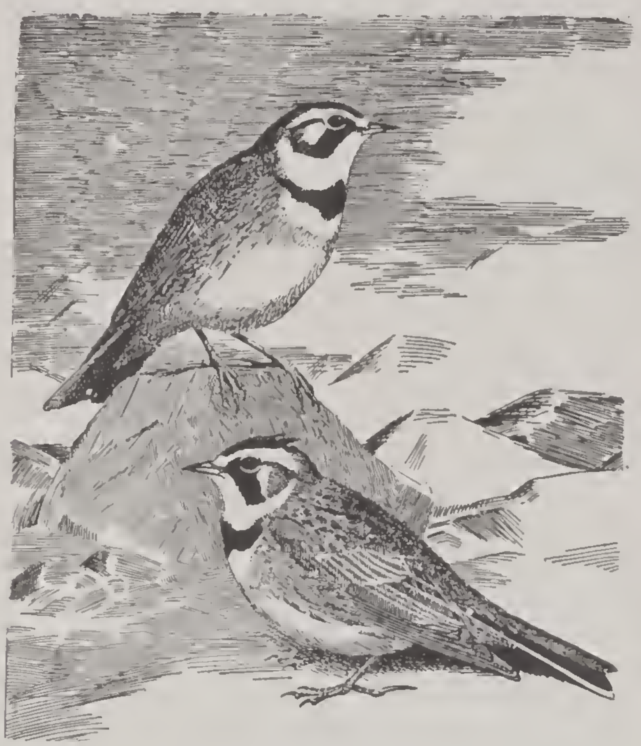


FIG. 87. Horned larks (from U. S. Dept. Agr. Farmers' Bull. 506).

Some Birds Fond of Fruits

There are a number of well-known birds that range over nearly all of the United States and southern Canada and that have a pronounced fondness for fruits and berries, especially cherries, grapes, and blueberries. Losses may be considerable in local areas or in dry seasons when there is a scarcity of wild foods. Many of these birds also consume a considerable number of insects, which are also the chief food of their nestlings.

The birds with the above habits are the catbirds, thrashers (Fig. 88), and mockingbirds (Mimidae); the thrushes (Turidae) which include the robin (Fig. 81); and the cedar waxwings (Bombycillidae). Most species migrate southward in the fall, but the robin may winter as far north as southern Maine and British Columbia. Two broods are usually reared per season.

The Woodpeckers (Picidae)

With a few exceptions all species of woodpeckers are beneficial. They are one of the chief defenders of trees against insect attacks. Wood-boring larvae and ants are their favorite food. The exceptions are the sapsuckers (Sphyrapicus spp., Fig. 89): the eastern yellow-bellied sapsucker, the western red-breasted sapsucker, and others that occur in varietal forms throughout the United States.

Some woodpeckers remain throughout the year in their breeding localities, but the yellow-bellied sapsucker migrates south for the winter months to the latitude of Ohio southward to Central America. It spends the summer in southern Canada and northern United States and nests in tree holes 20 to 50 feet from the ground in June.

Food and Damage. The usual diet of the sapsucker consists of insects such as bees, wasps, and ants, berries of various sorts, and the sap and inner bark of trees. Its typical injury to trees is a horizontal series of holes often in rings that run around the trees in a series of parallel rows extending up and down trunks or limbs. These series of holes are found in trees such as birch, apple, sugar maple, and pine. The English walnut is attacked in California. They feed on the inner bark of these trees and regularly return to lap

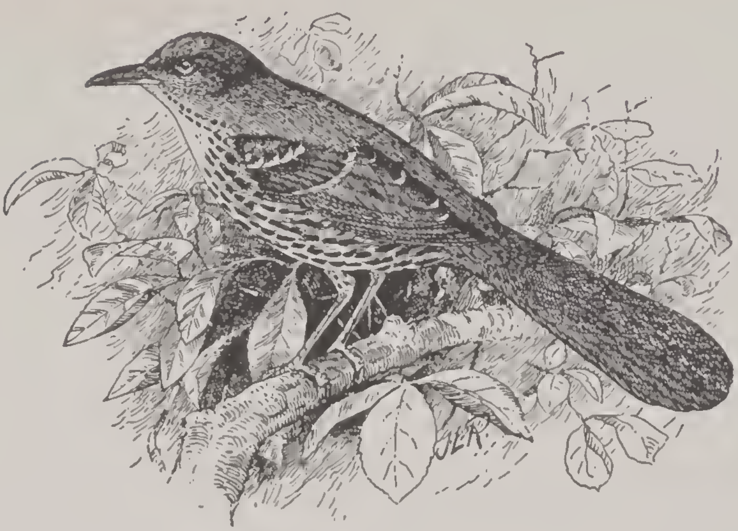


FIG. 88. Brown thrasher (U. S. Fish Wildlife Service Conservation Bull. 15).

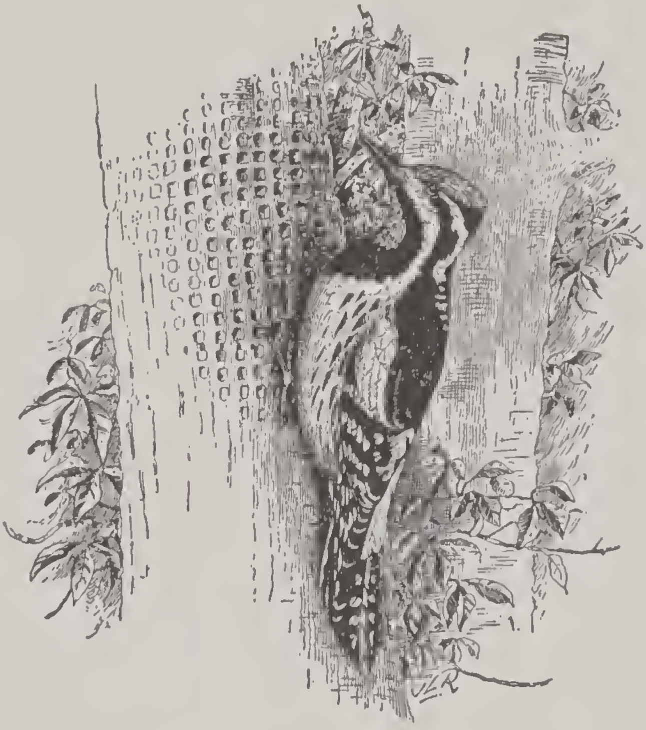


FIG. 89. Yellow-bellied sapsucker (from U. S. Dept. Agr. Farmers' Bull. 506).

up with their extensile, brush-like tongue the sap that oozes from the holes. In the winter they attack pine trees. This injury may weaken, disfigure, or even kill trees or individual branches in some cases. In addition, the holes may furnish a ready point of entrance for wood-rot diseases. Hardly a tree in some old apple orchards escapes attack by sapsuckers, but fortunately actual damage to trees or crops is usually not important.

QUESTIONS FOR DISCUSSION

1. Would you consider mammalian pests easier or harder to control than insect pests? Give reasons.
2. Agriculture has favored the increase of rodents. Explain how.
3. Animals with the greatest chance for survival generally have the fewest number of young. Present reasons for this.
4. Compare hibernation in ground squirrels to that in insects.
5. Why may we consider woodchucks of some value on non-agricultural lands?
6. Differentiate between ground squirrels, tree squirrels, and chipmunks.
7. Why are pocket gophers difficult to control?
8. Rats and mice persist in abundance in spite of continuous campaigns to eradicate them. Why?
9. Would the complete eradication of rats be desirable from the standpoint of seriously affecting other animal populations?
10. Do rats and mice have any redeeming chracteristics?
11. Compare the different mice species as to their destructiveness.
12. What is the evidence of the presence of meadow mice in an orchard?
13. Why is pine mouse injury difficult to detect?
14. Are porcupines on the way to extinction because they produce only one (rarely two) young per year?
15. What injurious habits do hares or rabbits have?
16. Moles are often unjustly blamed for damage to root crops. Why?

17. Why are moles more of a pest on lawn or sod areas than on cultivated land?

18. Distinguish between signs of mole activity and those of pocket gopher activity.

19. What are some of the factors that determine the number of litters that a mammal pest may have in one season?

20. Why should bird control be practiced with discrimination?

21. What characteristics do birds have that make control difficult?

22. Account for differences in the appearance of a bird species?

23. Which birds are most injurious to crops—the gregarious or the solitary ones?

24. What species of birds has agriculture seemed to encourage? Why?

25. Is it desirable to eradicate a bird, such as the crow, if possible?

26. Enumerate the types of damage that may be caused by birds.

27. Why doesn't it do much good to winter-roosting areas to kill crows in those areas?

28. What birds may be classed as being more injurious than beneficial?

29. How injurious is the yellow-bellied sapsucker to trees?

30. What do birds do in cold climates in place of hibernation?

31. Are there any injurious birds in northern areas during the winter months?

32. What environmental factors may lead to increased crop destruction by birds?

Chapter 12

CONTROL OF VERTEBRATE ANIMAL PESTS

Vertebrate animal pest control, like insect control, includes both natural factors and applied measures. The natural factors consist of adverse weather conditions, forest fires, floods, predators, parasites, diseases, unfavorable habitat, and insufficient food supply. Any one or more of these factors may operate at various times to reduce populations or to cause population fluctuations known as cycles.

NATURAL CONTROL FACTORS

Both floods and forest fires may wipe out whole animal populations in an area, but immigration from outside areas usually restores populations again within a few years, providing food and normal cover are available. Predators, parasites, diseases, and insufficient food undoubtedly take their heaviest toll when rodent populations are at their peak and are major factors in population decline. Predators such as owls, hawks, snakes, weasels, shrews, skunks, dogs, and cats may be of much help in keeping rodent populations within bounds under environmental conditions unfavorable for the rodents (Fig. 90). Wildlife research indicates, however, that predators do not greatly affect the normal rodent populations under normal, stable conditions over a wide range and that any more rodents than a certain number fixed by the environment will ordinarily be destroyed in one way or another. Predators may keep rodent populations down under conditions such as low rodent population levels, insufficient cover, and high predator population levels. Ocasionally predators may become destructive to livestock or poultry and must be destroyed, but the great majority of wild predators should not be attacked as promiscuously as is often done.

APPLIED CONTROL MEASURES

Applied methods of animal pest control require good judgment and discrimination because a bird or mammal species may be valuable in one area and quite destructive in another; or it may be valuable in one season of the year and destruc-

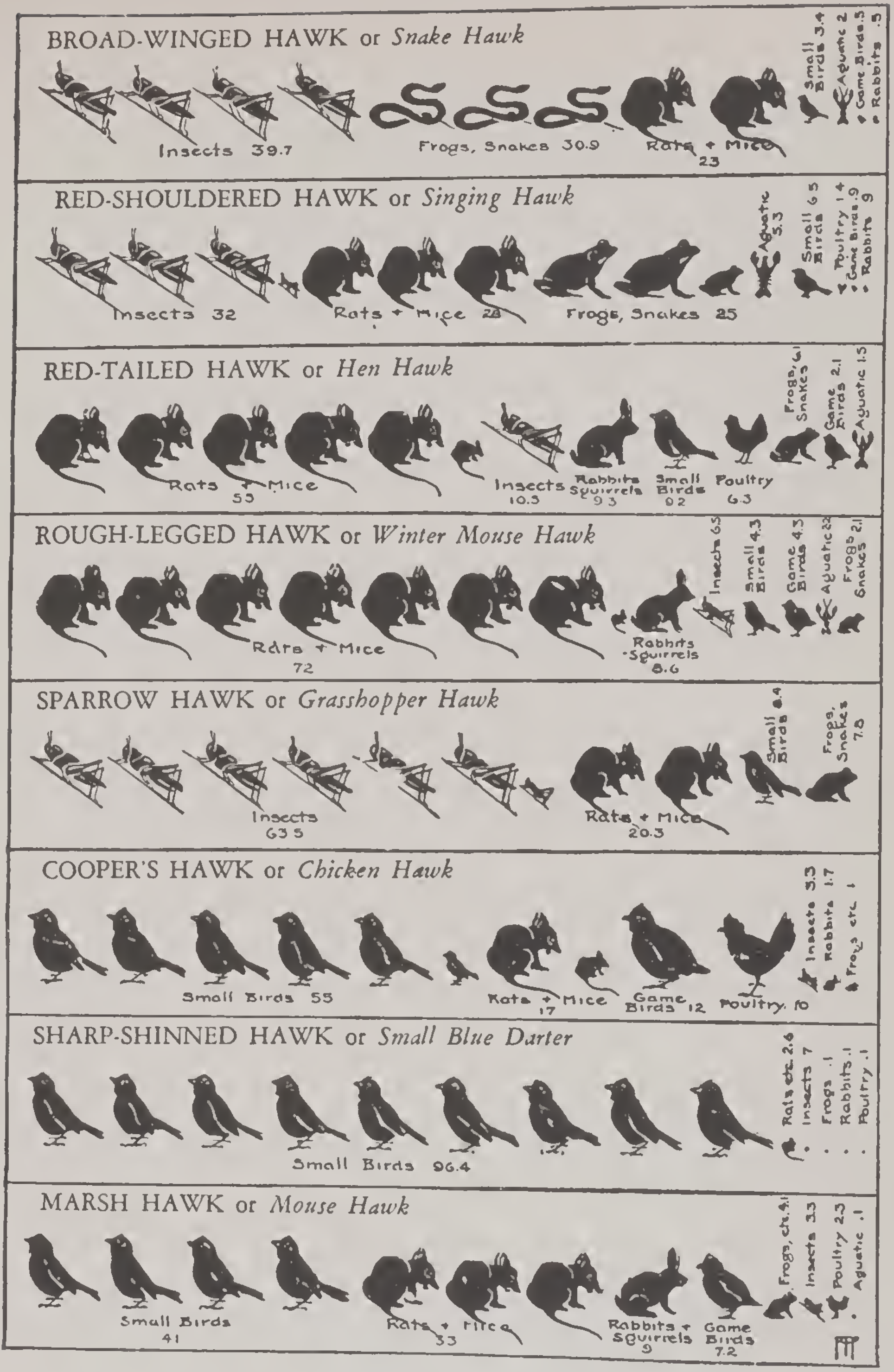


FIG. 90. The food of some of our common hawks (National Association of Audubon Societies, based on studies made by the U.S. Dept. of Agriculture, in U.S. Dept. Agr. Circ. 370).

tive in another. For this reason the objective should never be total extermination, for most species, but should merely be a reduction in population to reduce damage to the minimum. The beneficial characteristics of potential pests should be utilized whenever possible, and their presence discouraged wherever they are injurious.

The applied measures of harmful bird and mammal control consist of: (1) the indirect approaches of avoidance of damage through modification of farm practices; substitution of crops less vulnerable to attack; management of populations through the creation of favorable or unfavorable habitats; the use of protective barriers and of frightening devices; and (2) the direct or aggressive approaches of poisoning, trapping, and shooting. As far as it is possible or practical the indirect methods of control should take precedence over the direct methods.

Indirect Methods of Control

MODIFICATION OF FARM PRACTICES. This may consist of several important procedures, the practicability of which each grower must determine under his own conditions:

1. Removal of crops (particularly grain crops) as soon after ripening as possible before crows, blackbirds, waterfowl, or rodents have congregated. Corn or other grain left in shocks in the fields is an open invitation to birds and rodents to come and get it. Early Prolific rice escapes damage from blackbirds because it is harvested before large flocks arrive.
2. Alteration of time of planting to avoid bird or rodent damage to seeds or transplants. Seed sown early in the spring and young transplants set out early when food is scarce are subject to both rodent and bird attack. It has been often observed that, when young cabbage plants are set out before there is ample grass growth, cottontail rabbits will destroy nearly all the plants, but, generally, if planting is delayed until there is ample grass growth, little damage is done. Birds whose flocks have not yet broken up for breeding purposes may cause great damage to early sown grain fields. Crows and blackbirds are especially guilty in this respect.
3. Avoiding heavy mulches in gardens and under fruit trees, since these encourage mice and rats. Mulches under fruit

trees should be kept a few feet away from the tree trunks to discourage girdling by mice. Straw mulches on strawberries should not be put on until late fall so as not to encourage the congregation of mice which may damage the plants severely.

4. *Harvesting as clean as possible*, because crop residues left out in the fields and orchards encourage birds and rodents.

5. *Growing wild or cultivated buffer crops* to supply potential pests with ample food so that they will leave the main crop alone. Patches of soybeans around a garden usually keep rabbits out of the garden. Hedgerows of berried shrubs, trees, or other wild fruits relished by birds may help keep birds from damaging fruit in an orchard. Fruit-tree prunings left on the ground under the trees will supply rabbits with food so that they will leave the trees alone.

SUBSTITUTION OF CROPS LESS VULNERABLE TO ATTACK. Where damage is severe, this may involve a complete change in the type of farming. Most growers are reluctant to resort to such a cure unless the pests force it on them. It may be possible to use varieties that escape damage at seeding time, because they can be planted later, or to use varieties that mature either earlier or later and can thereby escape specific pests.

MANAGEMENT OF POPULATIONS. This may involve the elimination of favorable breeding sites or the creation of favorable breeding sites where population build-up may be either encouraged or discouraged. The elimination of favorable breeding sites such as rubbish piles, stone piles, brush heaps, and rank growth works best for rodents, whereas the creation of favorable breeding sites works best for birds with habits that are amenable to management. In the case of starlings, their nesting populations may be managed by providing them with wooden nests placed on poles or trees 10 feet above the ground. When conditions warrant it, the number of nesting birds or their eggs could be reduced. Bird houses for many other species of birds can be erected so that their population in an area may be controlled to some extent.

PROTECTIVE BARRIERS. Protective barriers may involve physical barriers and chemical or repellent barriers.

Physical barriers may be in the form of fences to keep animal pests out of a given area; in the form of screen wire or cloth tents or cages to protect fields of plants or individual plants from bird or mammal pests; and in the form of electric fencing to shock animals or birds coming in contact with it. Woven-wire fencing of 1-inch mesh and 2 to 3 feet high is useful in keeping rabbits and woodchucks out of cultivated areas, especially if, to discourage burrowing, the lower 4 to 6 inches is flattened outwards on the ground and covered with soil. Deer fences should be 7 to 9 feet high with the upper portion made up of two or three strands of barbed wire.

Hardware cloth, 1/4-inch mesh, or concrete placed vertically some 30 inches into the ground and a few inches above it should make an effective barrier for moles, gophers, and pine mice in small garden areas (Fig. 91). Hardware cloth

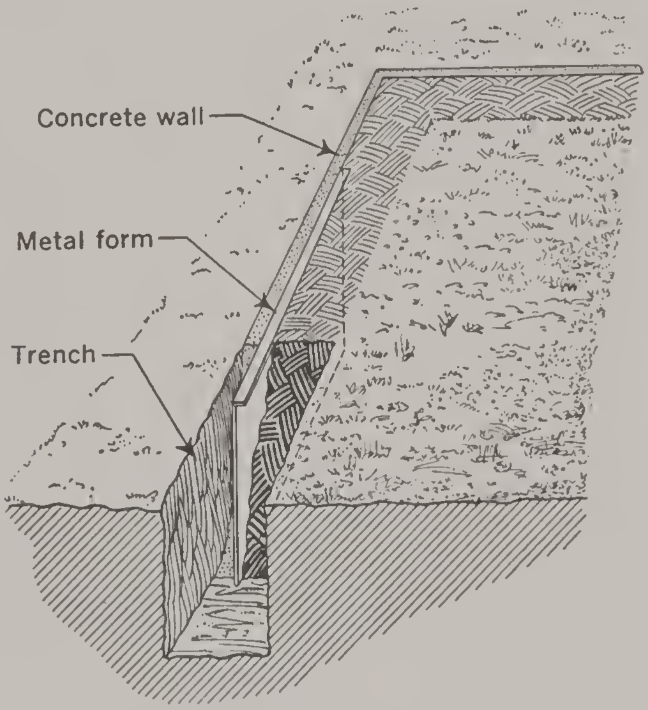


FIG. 91. Method of construction of a concrete barrier 1 inch thick and 30 inches deep to exclude burrowing animal pests from areas where valuable plants are growing. Concrete is poured on the outside of metal forms while earth is filled in on the bed side. The form is moved forward without waiting for the concrete to dry. (U. S. Dept. Agr. Circ. 381).

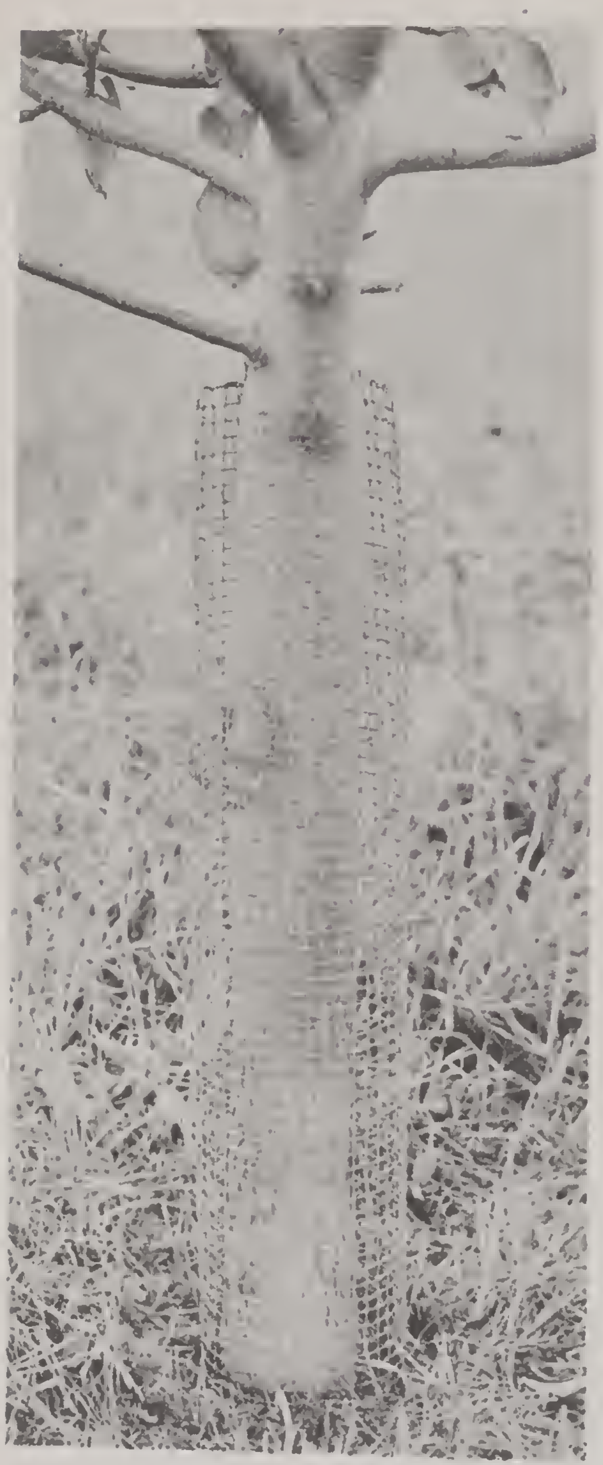


FIG. 92. Hardware cloth (1/4-inch mesh) placed around young fruit tree to protect it from rabbits and mice.

wrapped loosely around the trunks of young fruit trees (Fig. 92) from the roots to 2 feet above ground provides good rabbit protection and some mouse protection in the winter, providing snows are not so deep that feeding may take place above the guards. Roofing paper and veneer bands may be used in a similar manner but should be removed each spring. Small plantings of blueberries, strawberries, peas, and other crops attractive to birds may be protected by coverings of cheesecloth, tobacco cloth, or wire screening (Fig. 93). These may be of a permanent or semi-permanent nature, with frames to hold the material away from the plants. Rat-proofing of buildings with cement, hardware cloth, and metal flashings may also be included under physical barriers.

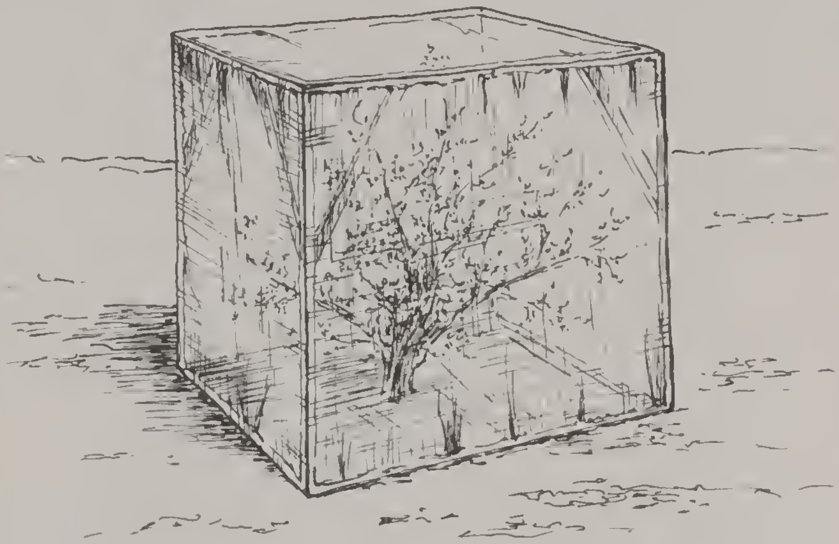


FIG. 93. A wooden frame covered with tobacco cloth or wire screening, when placed over blueberry bushes, provides effective protection from birds and insects.

CHEMICAL BARRIERS. These consist of materials, placed on or near the plant or plant part, that are distasteful or repulsive to the pests and thus deter them from feeding. The best example is coal-tar products to coat corn seed to make it repellent to crows, other birds, and rodents. Ground tung seed produced in the extraction of tung oil is reported to be repellent to deer. Various materials such as dried blood and tobacco dust dusted or sprayed on garden plants are reported to be repellent to rabbits, but frequently the repellency is only temporary. So far, no persistent repellent has been found for green foliage. Rabbit Repellent 96A developed by the U. S. Fish and Wildlife Service has been found effective during the winter for the protection of the bark of trees and shrubs from rabbits and field mice. It is applied as a spray or with a paint brush after the trees are dormant. One application usually gives protection for the whole winter. One gallon of the material covers 200 to 400 trees depending on their size. Moles are easily repelled from runways in which foreign materials such as naphthalene, lye, and many so-called poison mole baits are placed at intervals.

Many other paints or smears to repel rabbits or mice from bark have been developed, but many either do not give full winter protection with one application or injure the trees.

FRIGHTENING DEVICES. Frightening devices may work through sound effect, movement, or appearance. They are most often used to frighten birds from fields or trees but may also be useful in frightening away deer, rabbits, and other mammal pests. The chief difficulty is that the birds or mammals get used to them so that they must be changed at intervals to be effective.

Scarecrows, especially if some motion can be imparted to them, may be effective in frightening crows and sometimes other birds from fields of newly planted grain. Use of living predatory birds such as vultures, hawks, and owls may also be effective in individual cases. Stuffed specimens have been tried, but birds get used to them.

The placing of flags made of strips of cloth or paper on stakes or sticks at 25-foot intervals often gives protection from birds. A further refinement of this method, referred to as continuous string flagging, consists in running strings between the stakes and fastening cloth or paper streamers (2 by 24 inches) to it at 5-foot intervals. Waxed-paper streamers may make a snapping or crackling moise in a breeze and further add to the effectiveness. This method has been found valuable for horned larks in California.

Various noise-making devices have been tried but generally have been found uneconomical or impractical. A shrill whistle or a shotgun blast is effective in frightening mammals or birds, but unless it can be repeated at intervals over the whole area to be protected it may not work. An automatic acetylene exploder has been effectively used in some localities.

Direct Methods of Control

Poisoning, trapping, and shooting are the more aggressive methods of animal pest control but should only be used under the direction of qualified persons, so as to reduce to the minimum the danger of destroying beneficial wildlife.

POISONING. Poisoning is generally accomplished with poison baits or through fumigation or gassing. The chief objection to poison baits is that they are non-selective, but they are the cheapest and most efficient method of dealing with many injurious mammals. They should not be used against birds because many beneficial ones may be killed. Even for mammals, experience and care is necessary to avoid needless destruction of beneficial wildlife. The success of poison baits depends on their proper preparation and application. They are generally placed in the trails or in or near the burrows of the animals to be controlled but should be so concealed so that beneficial wildlife will not easily find them (Fig. 94).

Poison baits have been successful for mammals such as ground squirrels, mice, pocket gophers, prairie dogs, rabbits, rats, and porcupines. Some poison baits for moles are on the market, but a proven, successful one has yet to be found. They may be used during the growing season and on non-hibernating forms during the winter. For most rodents and rabbits the baits with which poisons are incorporated generally consist of some grain such as oats or corn, or some legume such as alfalfa or clover. Chicken mash, cereals, ground fish, ground meat, vegetables, and fruit may be used for rats and mice. Prebaiting for a week or more is desirable for rats to determine what food they prefer to eat and to dispel suspicion of the food. Porcupines are very fond of salt; therefore salt is generally used as the bait for attracting them. Root vegetables cut into large cubes are best for pocket gophers (Fig. 94). It is well to note that, if there is an abundant supply of unpoisoned food about, it is usually valueless to use the same food in poisoning operations. It is generally best to supply an attractive food to which the mammals do not have ready access.

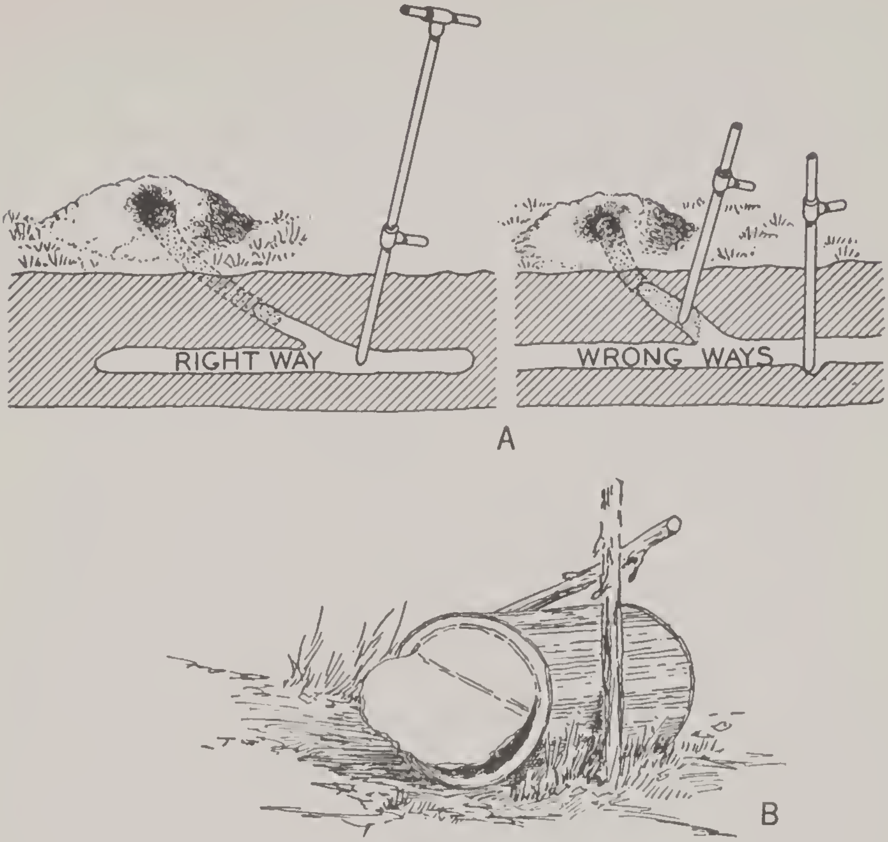


FIG. 94. Methods of placing poison baits. A, pocket gopher control. Bait is dropped down the hole made by a prod, and the hole is plugged immediately (U.S. Fish Wildlife Service Conservation Bull. 23); B, mouse control. Bait placed in tin can is protected from the weather and beneficial animals (U. S. Dept. Agr. Circ. 381).

POISONS USED IN POISON BAITS

Different, acceptable baits should be used on successive days, because rats quickly become suspicious of poisoned bait that killed some of them or made them sick, and they will not touch it. Baiting should be done throughout an infested area at the same time, to get as many rats as possible before they refuse to take bait.

Strychnine powder is widely used in poison baits, since it is highly poisonous and quick acting. It is obtained from the leaves of the plant Strychnos nux vomica, family Logoniaceae. Its bitter taste may be obscured by mixing it with an equal amount of baking soda when the poison-bait formula is being prepared. A typical poison-grain formula for general use on rodents is made as follows:

Strychnine alkaloid	1 oz.
Baking soda (bicarbonate of soda)	1 oz.
Gloss starch	1 tbs.
Water (hot)	1 pt.
Oats	16 qts.

> Heat the first three ingredients in the water until a thick paste is formed, then stir the paste into the oats until every grain is coated. For increased attractiveness, 1/4 pint of heavy corn syrup and 1 tablespoon of glycerine may be added to the above mixture.

One or two teaspoonfuls of strychnine-treated whole corn or oats placed near (not in) each ground squirrel burrow entrance is highly effective in eradication.

White arsenic and thallium sulfate, high-grade and finely ground, at about the same strength as strychnine, may also be used in making poison baits. Both are tasteless and odorless and have been employed for rat baits. Neither of these two poisons, however, kills rodents as quickly and readily as strychnine, but both are just as deadly to man and to domestic animals.

Zinc phosphide (Zinc Phosphide Rodenticide) is widely used for the control of outdoor mice, and, to a lesser extent, of rats. It is cheaper than strychnine and less dangerous to wildlife, because it loses its toxicity under exposed conditions in about 2 weeks. It is dusted on cubed apples, carrots, sweet potatoes, or crushed oats, and the baits are distributed in partly open tin cans in holes and in protected runways of the mice, so that other animals or birds will not readily find them.

Red squill is a lily-like bulb that has toxic properties of special value in rat poisons. It has the advantage of being relatively harmless to man and to domestic animals but is poisonous to rats, which do not vomit. It is marketed in both liquid and powder forms and is processed so as to have a uniform potency. The powder is generally mixed at the rate of 1 part squill to 9 parts bait by weight.

Alpha-naphthyl thiourea (Antu) is a recent discovery in the field of rat poisons, but it has been somewhat disappointing in rat control, because rats, who do not take a fatal dose, acquire temporary immunity to it. In addition, it is toxic to other animals and must be handled carefully. In poisoned baits it is used at the rate of 3 parts of pure Antu to 100 parts of food by weight. It may also be dusted in the form of a 50 per cent dust on the runways of rats or in their holes, to act as a tracking agent, since rats pick it up on their feet and in cleaning them get the poison in their mouths. Best results are obtained with Antu when it is used liberally with baits and as a tracking agent only once a year.

Wettable 50 per cent DDT has recently been reported as an effective tracking agent for house mice.

Warfarin. (3-(alpha-acetonylbenzyl)-4-hydroxycoumarin). This synthetic chemical, marketed in powder form, is a highly effective poison for the control of Norway rats and house mice, and may partially replace the other poisons in poison baits. Warfarin is evidently odorless and tasteless in the dosages employed, since rats accept it readily with attractive baits and do not become wary of them. Warfarin, when consumed in small quantities over a period of 1 to 2 weeks, destroys the clotting property of blood and produces a slow, painless death through internal hemorrhage. One single dose is rarely fatal. Best results are obtained with cereal-type baits such as yellow corn meal or/and rolled oats in which the poison concentration is 0.025 per cent. This concentration gives minimum danger for other animals but may be harmful when consumed over a long enough period; therefore, supplies of warfarin bait should generally be kept in protected feeding stations. Warfarin or ready-to-use warfarin baits may be obtained under various trade names.

FUMIGATION OR GASSING. This method is both cheap and effective and has been successful for burrowing rodents such as woodchucks, prairie dogs, ground squirrels, and to a lesser extent for pocket gophers, moles, rats, and some birds that nest in enclosed places. Gassing is best done in the early spring before the young appear and when there is little danger of destroying beneficial forms of wildlife that may use dens later in the season.

The most common fumigants are carbon disulfide and calcium cyanide (Cyanogas). Carbon disulfide is a heavy gas and tends to settle down into the burrows. It is applied by soaking the liquid into waste cotton balls that are then shoved into the burrows, or it is pumped into the burrows by means of a special pump. In either case the burrows are closed over with soil or sod after treatment. Calcium cyanide, marketed as a powder, forms a light gas on exposure to air moisture. The required amount is placed far down each burrow or blown in with a dust gun (Fig. 95), and the burrow is closed as with carbon disulfide fumigation. The U. S. Fish and Wildlife Service and some commercial companies have developed gas cartridges that are set off by means of a lighted fuse and are then pushed into the burrows of rodents. These cartridges are inexpensive and may be obtained through state agricultural agencies or horticultural supply stores.

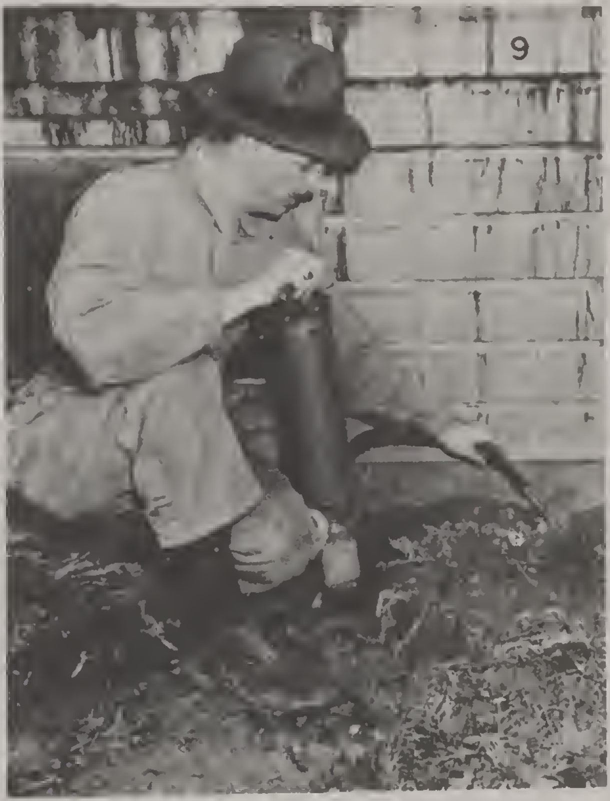


FIG. 95. Fumigating a rat burrow with "Cyanogas" (U. S. Dept. of Agriculture photograph).

When the burrows are extensive, greater amounts of the fumigants must be used for effective results. Because pocket gophers' burrows are intricate and the animals close off the gassed parts with earth the gophers are not readily killed by fumigation. Carbon monoxide gas piped into the burrows from a gasoline-engine exhaust for 5 to 10 minutes may also destroy rodents.

TRAPPING. Trapping is a widely used method for the control of many pestiferous mamals and birds. It is most successful when the habits of the pests are known, and the traps are set or placed accordingly. There are many different types of traps that may be purchased or made at home. Their description and applications follow:

Steel leg-grip traps are of various sizes. The smaller ones are effective for rats and rabbits, and the larger, more powerful ones are used for woodchucks and other large mamals (Fig. 96C). They are set so that the animal steps on and depresses a trigger pan which releases the steel springs of the trap so that the open jaws clamp onto the animal's foot. They are generally placed in burrow entrances, concealed in paths of the animals, or arranged and concealed around a bait. They should be examined daily.

Snap-back or guillotine traps that kill their victims instantly are of two sizes (Fig. 97). The small ones are for mice, and the large ones with powerful springs are for rats or squirrels. They are set in runways or on trees and may be baited or unbaited. When they are unbaited, it is best to enlarge the trigger by soldering to it a tin disc or square just small enough not to interfere with the descending bar (Fig. 96D). When the traps are baited, the bait should be fastened to the trigger with string or fine wire. To be effective for rats and mice these traps should be used several dozen at one time and examined and reset daily.

Wire cage and barrel traps are of various sizes and designs (Figs. 96A, B and 98) and may be used for mice, rats, or rabbits. Some of these traps are made to catch a number of animals at one time and are self-setting. They should be set in places where the animals are accustomed to feed and should be baited and made as inconspicuous as possible by covering with brush, branches, or hay. Birds such as crows or ravens may be captured in a large cage trap (Fig. 99) of special design, erected in fields.

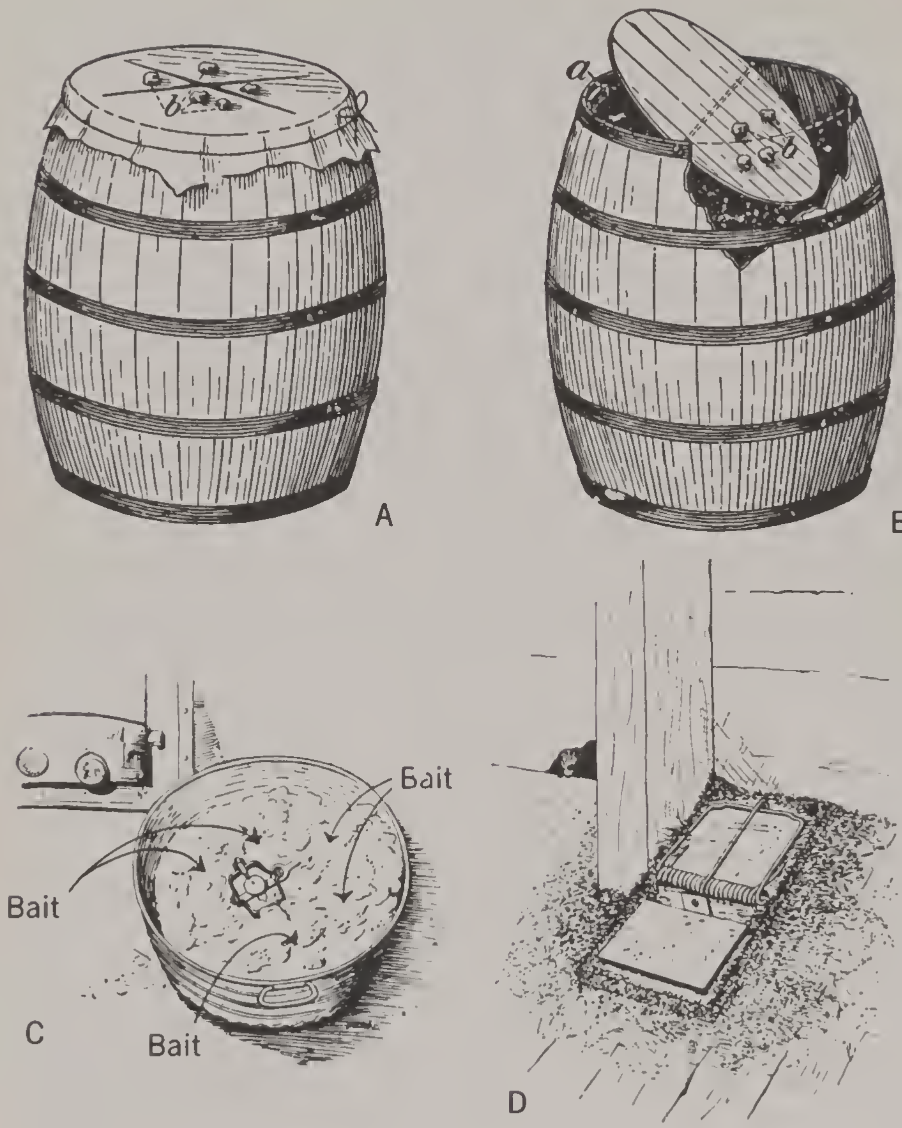


FIG. 96. Methods of trapping rats. A, B, barrel traps with b, bait and a, stop (from U.S. Dept. Agr. Farmers' Bull. 369); C, steel spring trap covered lightly with ashes; D, snap-back rat trap with enlarged trigger-pan set in rat runway and covered over lightly (Cornell Ext. Bull. 353).

Box and tile traps (Figs. 100 and 101) which may be made at home are quite effective for cottontail rabbits, especially during the winter when cover is scarce. Box traps should be made of weathered wood, should be set in protected places that the rabbits frequent, and may be baited or unbaited. The tile traps should be inspected frequently, and any rabbits found should be killed with the help of a dog or a gun. Various types of deadfalls and snares may be employed for rodents and rabbits, but care should be taken not to destroy dogs, cats, and other useful mammals in them.

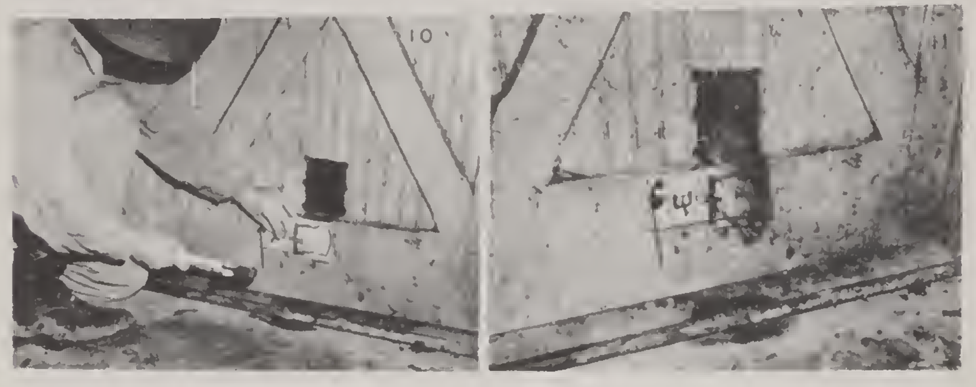


FIG. 97. A, B, a good place to set an unbaited snap-back rat trap (U.S. Dept. of Agriculture photograph).

Mole and pocket gopher traps are specially designed. They are effective if they are set correctly in the right place. Mole traps consist of the harpoon type (Fig. 102), most successful for shallow runways; the choker-loop trap (Fig. 103B); the scissors-jaw trap (Fig. 103A); and the diamond-jaw trap (Fig. 104), which may be used where deep burrows are made. The directions for setting these traps generally accompany them when they are purchased and should be carefully followed. Mole traps must be set on active runways; these may be determined by pressing down a small section of each runway and noting those that are repaired within a day.

Trapping is recommended for pocket gophers where infestations are light or are confined to small, limited areas. Gopher traps are inexpensive and are placed as shown in Fig. 103 C and D. The traps should be placed either in side or in main runways where freshly constructed mounds are located. The burrow should be left open or partly open to attract the gopher in repairing the break. Trapping may be supplemented by poisoning because some wary individuals will not be caught, and numerous young may be present that are too small to be caught in traps.

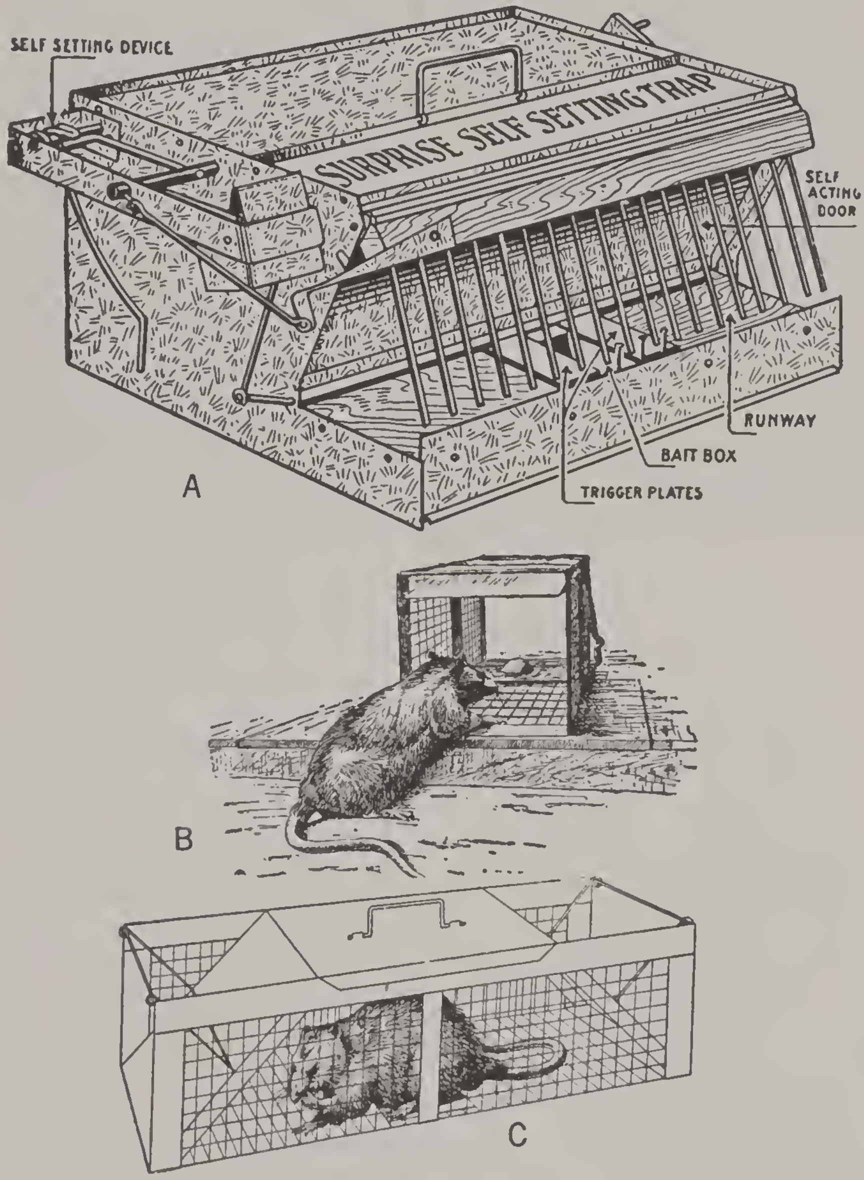


FIG. 98. Two types of cage traps suitable for small animals. A, a self-setting trap (Carter Carleton Mfg. Co.); B, Havahart trap set (Allcock Mfg. Co.); C, Havahart trap closed.

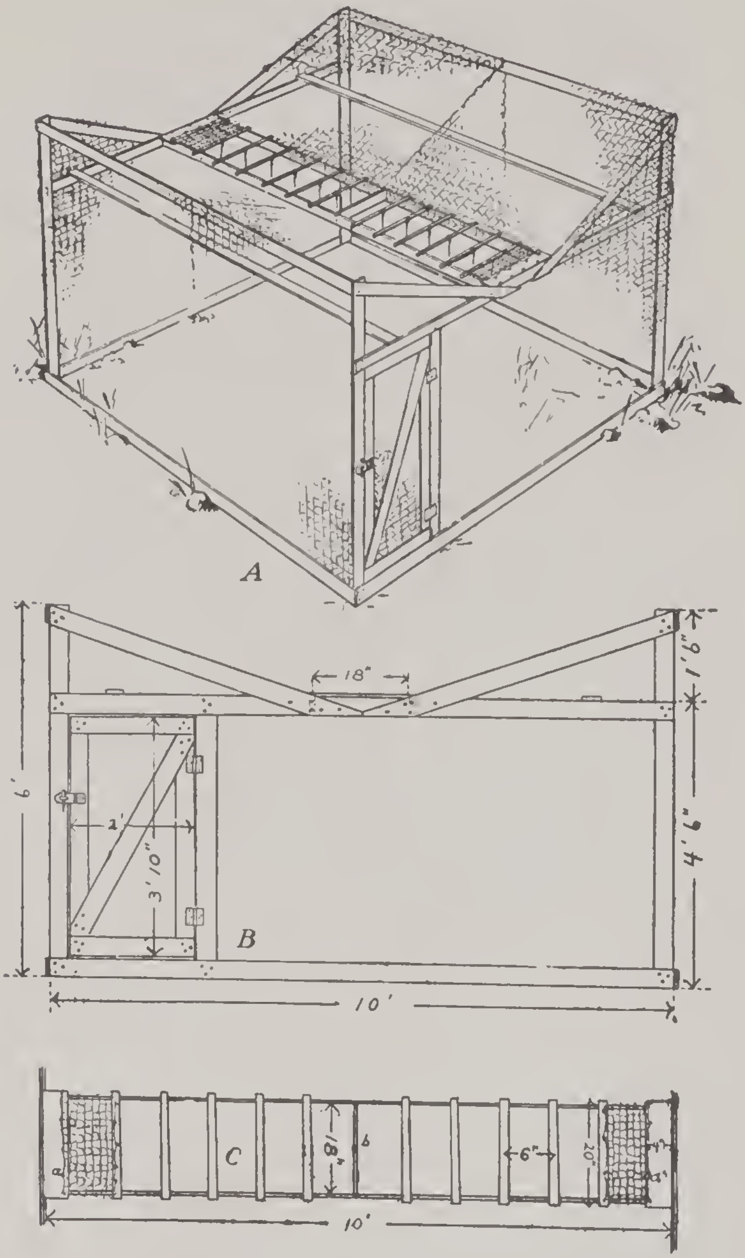


FIG. 99. Cage trap of Australian type for capturing crows, and details of construction; A, view of completed trap; B, plan of "ladder" opening; C, end elevation. (U. S. Dept. Agr. Farmers' Bull. 1102).

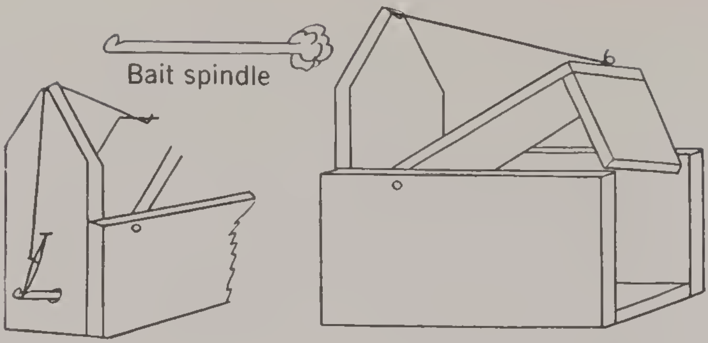


FIG. 100. A figure-4 box trap (9 x 9 x 20 inches) useful for rabbits and other small animals (Cornell Ext. Bull. 729).

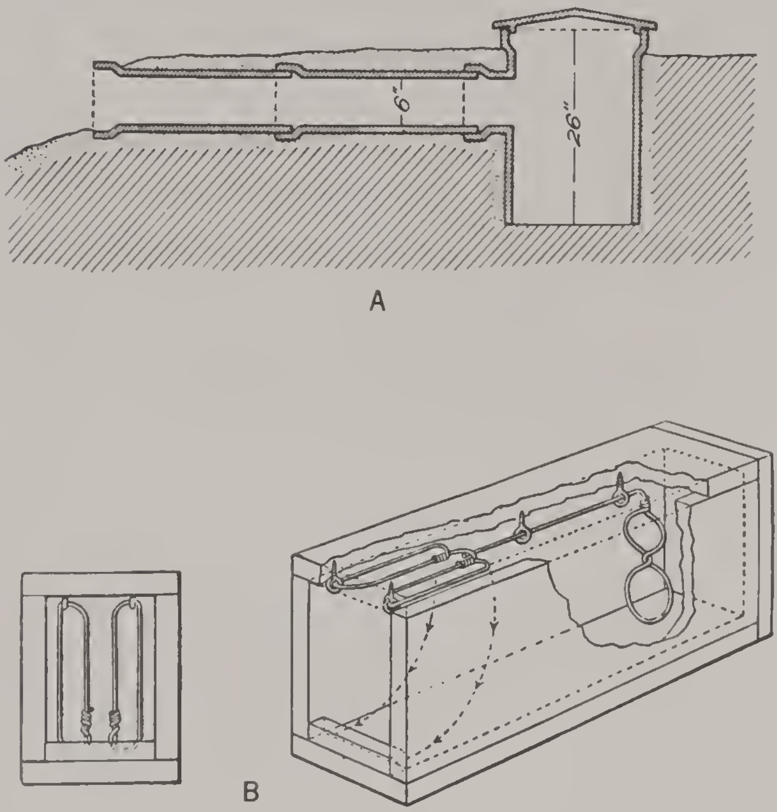


FIG. 101. A, cross section of a Walmsley trap for rabbits; B, a Wellhouse trap for rabbits (6 x 8 x 21 inches) (U. S. Dept. Agr. Farmers' Bull. 702).

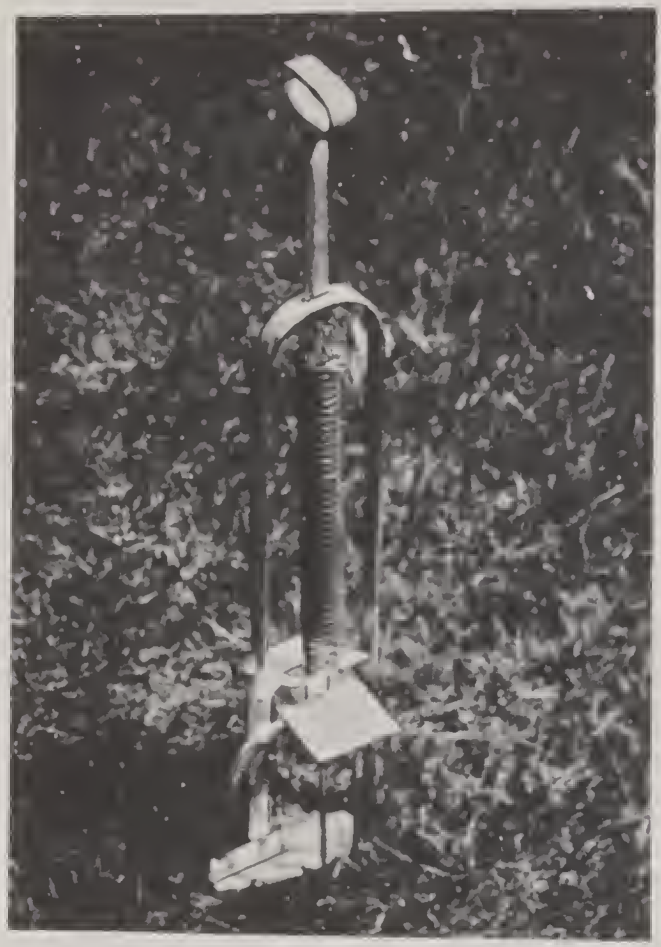


FIG. 102. A harpoon-type mole trap set over an active runway.

SHOOTING. The shooting of harmful mammals and birds by competent persons offers a selective method of destruction that may be both effective and practical, except in areas where the use of firearms is forbidden or where game laws protect the animals. In sparsely settled areas, small-bore rifles or shotguns may be used for rabbits, squirrels, woodchucks, rats, and harmful birds. A .20-gauge or .410-gauge shotgun is very effective in reducing cottontail rabbit populations in populated areas during the open season. However, promiscuous slaughter of mammals other than rats and mice and of harmful birds should not be encouraged. In some western areas drives are initiated, when rabbits or coyotes become too numerous, in which the animals are driven into specially constructed corrals and killed. The dynamiting of the winter roosts of crows at night in the west has resulted in enormous kills of crows and in the scattering of the flock's remains so that local damage is greatly reduced. Where winter flocks are doing no harm, however, their destruction

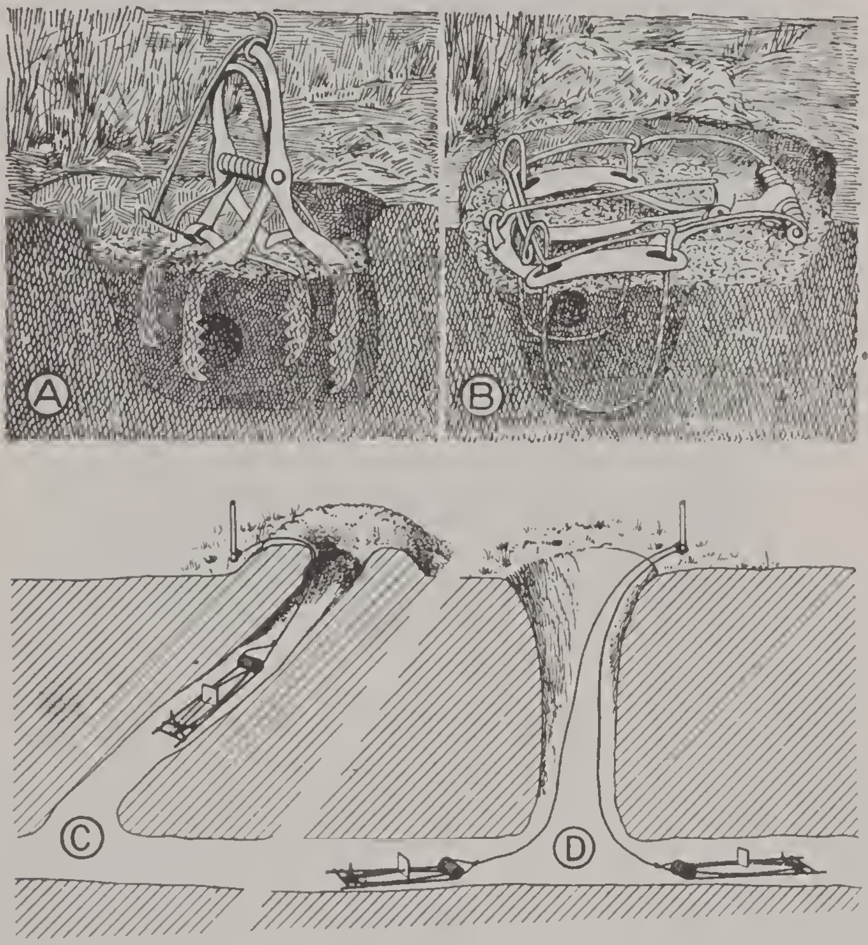


FIG. 103. Method of setting traps. A, scissors-jaw mole trap; B, choker-loop mole trap (U.S. Dept. Agr. Circ. 381); C, pocket gopher trap in side runway; D, traps in main runway; burrow should be left partly open (U.S. Fish Wildlife Service Conservation Bull. 23).

will not alleviate local conditions during the spring and summer, since these flocks migrate hundreds of miles northward to their breeding range.

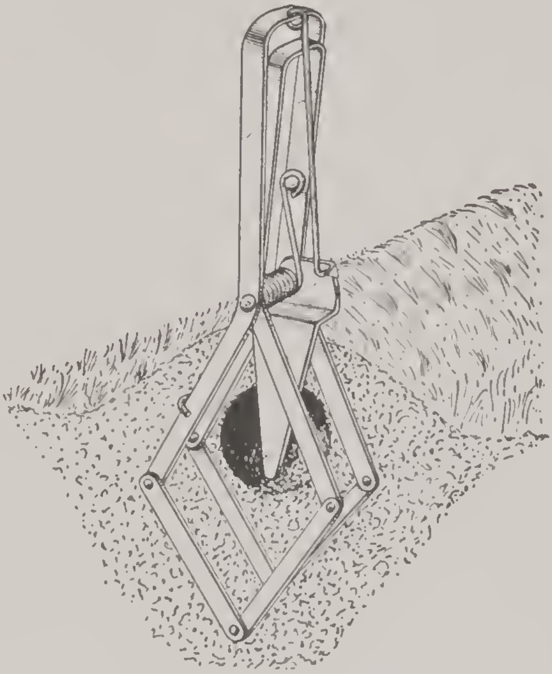


FIG. 104. Method of setting a diamond-jaw mole trap (U.S. Dept. Agr. Circ. 381).

QUESTIONS FOR DISCUSSION

1. How important are natural factors in the limitation of animal pests?
2. How can farm practices be modified to limit bird and rodent damage?
3. What bird and mammal species are most amenable to population management? Why?
4. For what animal pests can protective barriers be used? Chemical barriers?
5. What factors limit the practicability and usefulness of protective barriers?
6. Make some suggestions for protecting a small blueberry planting from birds. A large blueberry planting.
7. How practical are frightening devices for birds?

8. What are the objections to the use of poison baits for animal pest control?

9. Why should direct methods of control be carried on under the directions of a qualified person?

10. In gassing animal burrows, why is it important to know something of their design and size?

11. What are the factors that should determine the selection of a poison bait for a pest?

12. Why is prebaiting desirable for rats?

13. With what animal pests is the correct placing of poison baits important?

14. What are the good and bad points about the different chemicals that may be used to make poison baits?

15. Why are frequent changes in baits and poisons essential in rat control?

16. For what animals is gassing practical? Why?

17. Why is den fumigation best done in the early spring?

18. Why isn't fumigation very effective for pocket gophers?

19. Why should traps be used in large numbers for rat and mouse control?

20. Is trapping a selective method of animal pest control?

21. Rat control by one specific method is usually successful for only the first few nights. Why?

22. Why are box or tile traps for rabbit control more successful in the winter than in the summer?

23. What are the advantages and disadvantages in the use of firearms in mammal and bird pest control?

24. What is your opinion of the method of crow control by dynamiting their winter roosts?

25. Why is the control of mice by poisoning best done in the late fall?

Chapter 13

PLANT DISEASES

The study of plant diseases is known as plant pathology or phytopathology. It includes the study of the causes of plant diseases, their nature, and their control. When used in a broad sense, plant pathology includes plant disturbances attributable to all animals, large and small, and to all plants from the lowest to the highest forms, and all other factors that affect plant growth and crop production. In practice, however, the scope of plant pathology is generally limited to disturbances caused by microscopic organisms, viruses, and environmental factors (physiopaths). Insects, mites, rodents, and similar harmful organisms are covered in entomology or in economic zoology.

Plants, like animals, are beset by a multitude of diverse diseases caused by various living and non-living factors. These diseases are expressed as differences from the normal appearance or productiveness of the plants. A diseased plant may be defined as one that is continuously being irritated by a causal factor that upsets the normal activity of cells or organs so as to produce visible evidence of disease in the form of characteristic symptoms. This differs from an injury, which is only a momentary irritation resulting in injurious effects.

Plant pathology is a relatively young science in which many of the American pioneers are still active. Plant diseases themselves, however, are not of recent origin. References to blights, mildews, and plagues have been found in the earliest records of man. Throughout human history great plant disease epidemics (enphytotics) that brought famine and disaster to millions and that influenced the migrations of peoples have been recorded. The great famine of 1845 in Ireland and European countries was caused by an enphytotic of the late blight fungus on potatoes. Because plant pathology is a relatively new science, there is still some confusion in the standardization of terms.

No plant species or variety exists that is free from attack by disease. Most plants are susceptible to many disease-producing organisms, some of which may, under favorable conditions, wipe out the plants in local areas or even throughout their range. Our native chestnut trees are now only a memory of our fathers in most of their range because of the destructive chestnut blight, which was first observed in the New York Zoological Park in 1904. Some specific disease-producing organisms attack a wide range of different plant species, others attack only closely related species of plants, and still others are limited in their attacks to one or more definite varieties of the same species.

HEALTHY VERSUS DISEASED PLANTS

When is a plant diseased and when is it healthy? Generally a plant is considered healthy if it has the desired inherent traits; if it is grown under the best conditions with respect to soil, nutrients, moisture, air, and light; and if it is free from any insect attack, disease attack, and injury. Any departure from the optimum of any one or more of the above factors tends to produce a sick plant. Since plant species vary greatly in some of their requirements, the need for being well informed on the requirements of different crops is evident.

Various degrees of being sick are evidenced by plants. This depends how far from the ideal any one or more of the factors for health is removed. Since most plants do not grow under ideal conditions they might all look diseased to a varying degree if they could be compared with specimens growing under absolutely optimum conditions for growth or crop production. Since such an ideal comparison is impracticable, the more obvious symptoms of disease, such as abnormality of growth, color, habit, or crop, must be sought. The importance of knowing what are a plant's normal habits or requirements in order to be able to recognize any abnormalities cannot be overemphasized.

THE NATURE OF DISEASE ATTACK

A plant disease is generally characterized by a definite series of symptoms or symptom complexes that are expressions of that disease. Like any of our own common ailments, a plant disease does not generally produce one single symptom but produces a progressive series of symptoms, sometimes on different organs of the same plant. As an example, the brown rot of stone fruits may first appear on peaches as a blossom blight. From the blossoms the disease may travel into the twigs and produce girdling cankers that wilt and later kill the growth above them. Later in the summer the fruit may be attacked just as it is ripening to produce a rot that invades the entire fruit. The fruit may remain clinging to the tree, may gradually shrivel, and may become a mummy, from which the cycle may start all over again the next spring. A single disease attacking different plant species or different organs of the same plant may produce a variety of symptoms all forming a symptom complex characteristic of that disease.

Plant diseases may be either localized or systemic. A localized disease is one in which the causal organism is confined to definite organs or areas and does not spread internally to other organs of the plant. Leaf spots, scab, and fruit

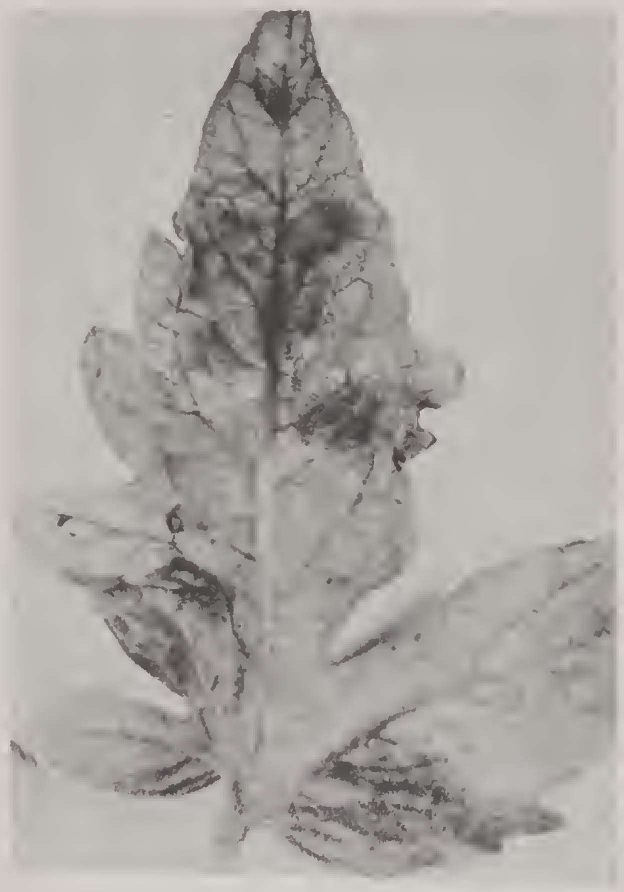


FIG. 105. Hydrosis caused by the late blight fungus of potato. Note white fungous growth around lesion.

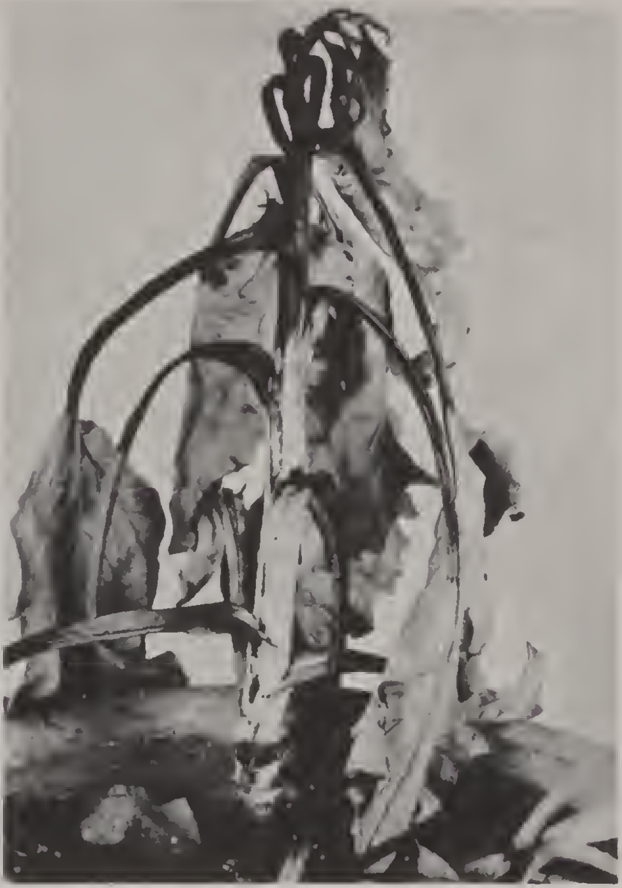


FIG. 106. Wilting of aster plant caused by a Fusarium fungus. Note white mold and blackened stem typical of advanced cases.

rot diseases are good examples of localized diseases. In a systemic disease the causal factor tends to spread internally and affect many parts of the plant. Most virus diseases are systemic. Some bacterial diseases such as fire blight and some fungous diseases such as fusarium wilt tend to become systemic.

THE DIAGNOSIS OF PLANT DISEASES

The health of a crop is dependent upon the grower's skill and knowledge. The grower must recognize at once when something is wrong and must make a diagnosis before he can

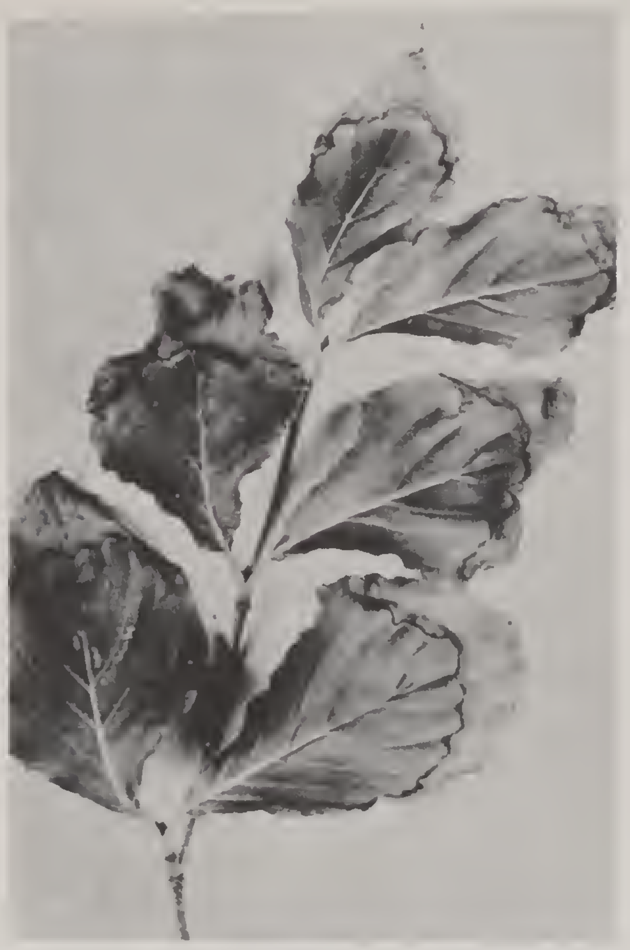


FIG. 107. Leaf scorch, caused by drought and high temperatures, on dogwood.

apply control measures intelligently. Diagnosis consists in telling diseases apart from a knowledge of their characteristic signs and symptoms. It is an art that requires constant experience and cultivation. Growers should have a knowledge of the general symptoms of the common diseases of their crops. Symptoms in many cases are so complex and confusing that the services of a trained plant pathologist are necessary to determine their cause correctly.

Symptoms are evidence of disease expressed by the plant itself because of the irritation or presence of some causal factor. Physicians generally make their diagnoses through symptoms—it is quicker and easier. Growers or plant doctors may also make their diagnosis through symptoms, but

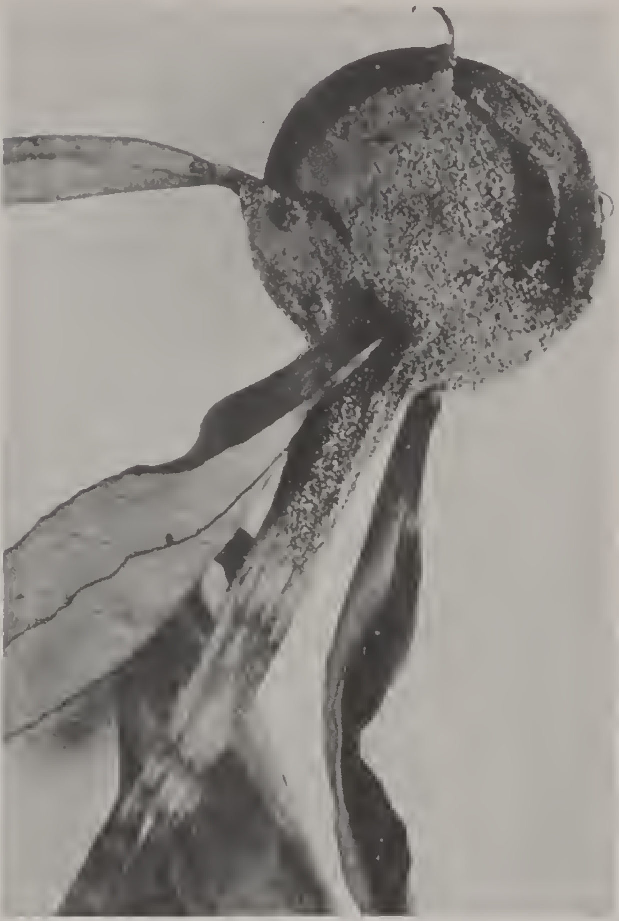


FIG. 108. Bud blight caused by Botrytis blight fungus of peonies. Note typical mold on affected area.

when diseases are difficult to diagnose by this means plant doctors, like medical doctors, search for signs—the causal organisms or factors producing the symptoms. Symptom complexes characteristic of a disease, together with any accompanying signs, constitute the cause and effect of a disease on which accurate identification is based. Such common symptoms as spots in leaves, dead areas in bark, rotten areas in fruits or tubers, abnormal swellings on roots, branches, and foliage, and abnormal color or habit are all expressions of the reaction of the plant attacked to the irritation of the disease-inducing factor.

THE CLASSIFICATION OF PLANT DISEASE SYMPTOMS

Symptoms may be either lesional or habital. Lesional symptoms are those confined to definite areas, and they show structural changes known as lesions in the epidermis or bark. Leaf spots, galls, cankers, and rots are examples of lesional symptoms. Habital symptoms are unnatural or abnormal habits that result from generalized disease effects. Abnormal foliage color, wilting, curling, and stunting are examples of habital symptoms.

Symptoms may be either primary or secondary. Primary symptoms are those occurring on the plant at the point of attack of the organism. Secondary symptoms are those occurring on some other part or parts of the plant as a result of the irritation or injury produced at the primary point of attack. For example, in crown gall the large, knotty growths

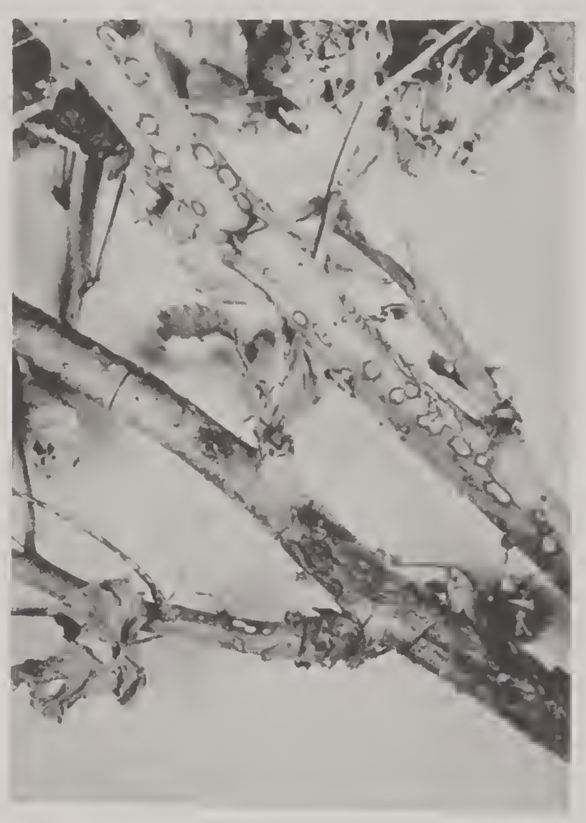


FIG. 109. Anthracnose of raspberries produces spots on stems.

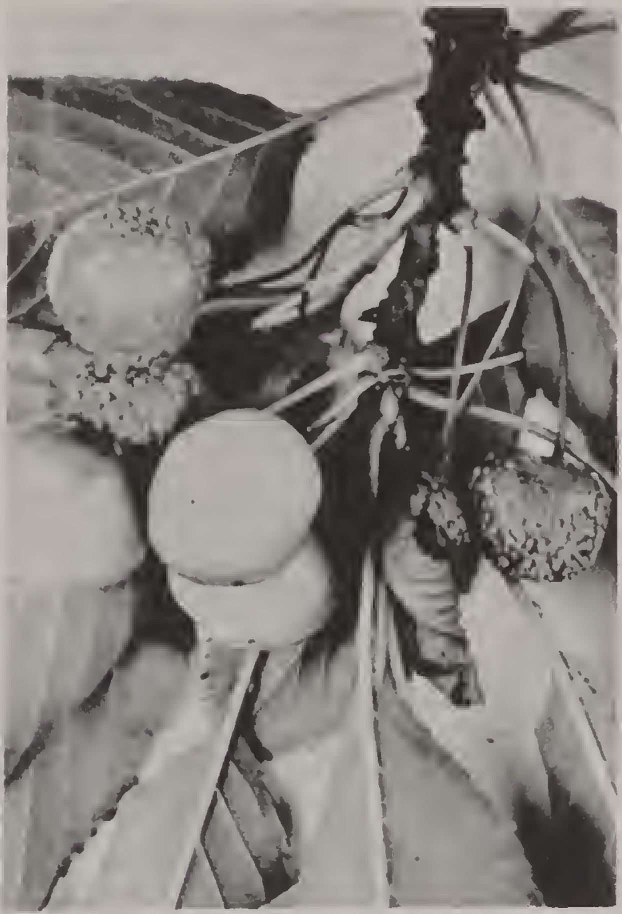


FIG. 110. Brown rot of cherry. Note mummy being formed.

on the roots or crowns of raspberries and other fruits are primary symptoms, but the stunting of the plants and the yellowed foliage resulting from these growths are secondary symptoms. The canker caused by brown rot on a peach twig is a primary symptom, whereas the wilting of the foliage and the death of the twig above this canker is a secondary symptom. It is very important in disease diagnosis to differentiate between primary and secondary symptoms. Primary symptoms should always be sought if symptoms are suspected of being secondary. Yellowed leaves, for example, may be either a primary or a secondary symptom of disease. If the causal factor cannot be located on or in the leaves after careful examination, it is reasonable to suspect that this is a sec-

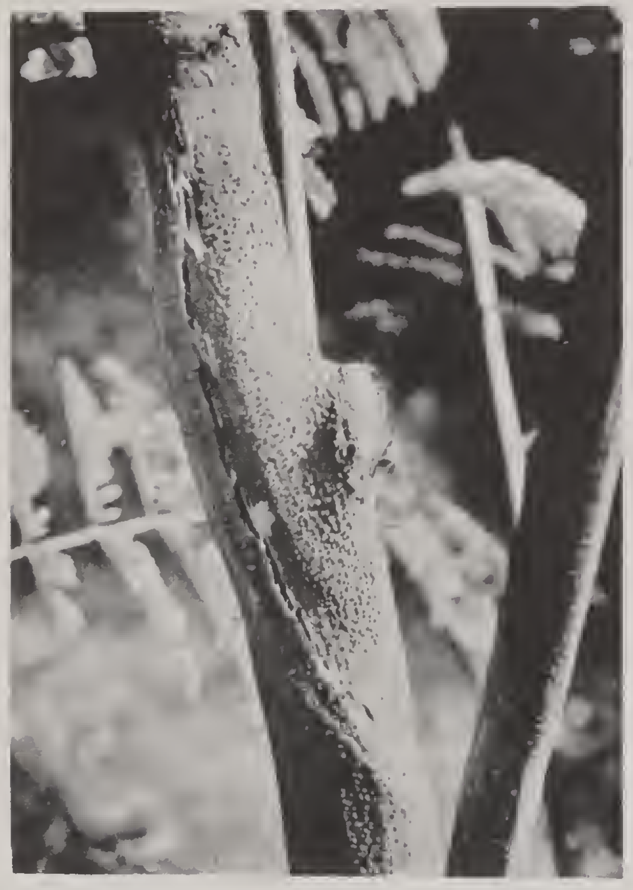


FIG. 111. Canker caused by Nectria spp. in the limb of a shrub. Note pruning wound through which infection started.

ondary symptom. The primary symptom or factor involved should be sought elsewhere on the plant or in its environment.

TYPES OF SYMPTOMS

Symptoms of plant disease fall into three main types: (1) those in which the outstanding characteristic is the dying or death of cells, tissues, or organs (necrotic symptoms); (2) those in which the predominating characteristic is underdevelopment of or stopping of growth of cells, tissues, or

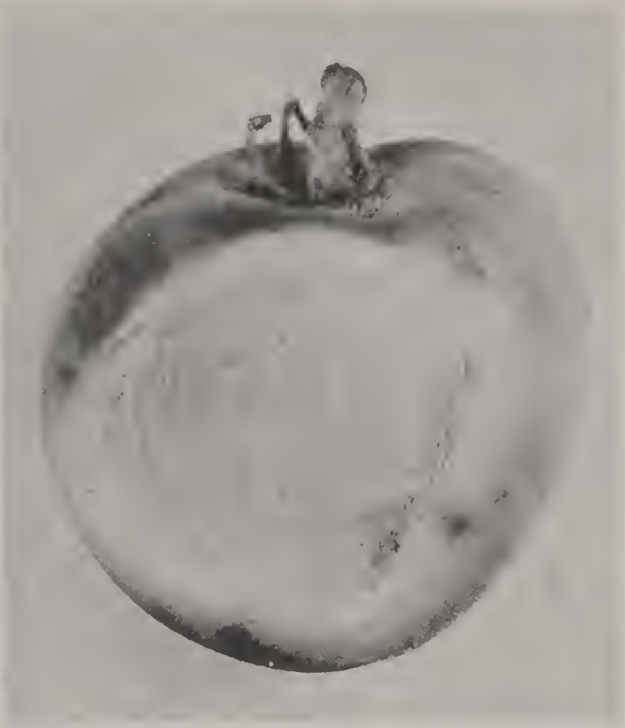


FIG. 112. Scald on tomato caused by heat from sun.

organs (hypoplastic symptoms); and (3) those that feature overdevelopment of cells, tissues, or organs (hyperplastic symptoms).

During its course a disease may exhibit symptoms that fall into any one or more of the three classifications, since all disease processes eventually tend to end with death of the whole plant or some of its parts. Care must be taken in classifying a disease to select the predominating reaction as necrotic, hypoplastic, or hyperplastic. It is often difficult to decide which of the responses is the dominant one, and differences of opinion may be expected.

Necrotic and hypoplastic symptoms may be localized in certain organs or parts of them, or they may be general, resulting in the death or stunting of the whole plant. Hyperplastic symptoms are usually primary symptoms of a lesional character, but in some cases they may be habital. Hyperplastic types of diseases may as they progress show either secondary hypoplastic or necrotic symptoms or both.

Some Common Necrotic Symptoms

YELLOWING. The yellowing of normally green tissues (usually foliage), due to a breakdown of chloroplasts or chlorophyll. When yellowing is generalized, involving all the foliage of a plant, it is usually a secondary symptom and may be caused by a disease-producing organism that has attacked some other important organs or by an unfavorable environmental condition.

HYDROSIS. A water-soaked condition of tissues caused by water leaving the cells and filling up the intercellular spaces. This is the first symptom to be noted in many foliage diseases such as late blight of potatoes and tomatoes (Fig. 105).

WILTING. The flaccid condition of leaves or shoots caused by a loss in turgidity (Fig. 106). This is usually a secondary symptom due to some trouble in the conducting system of the

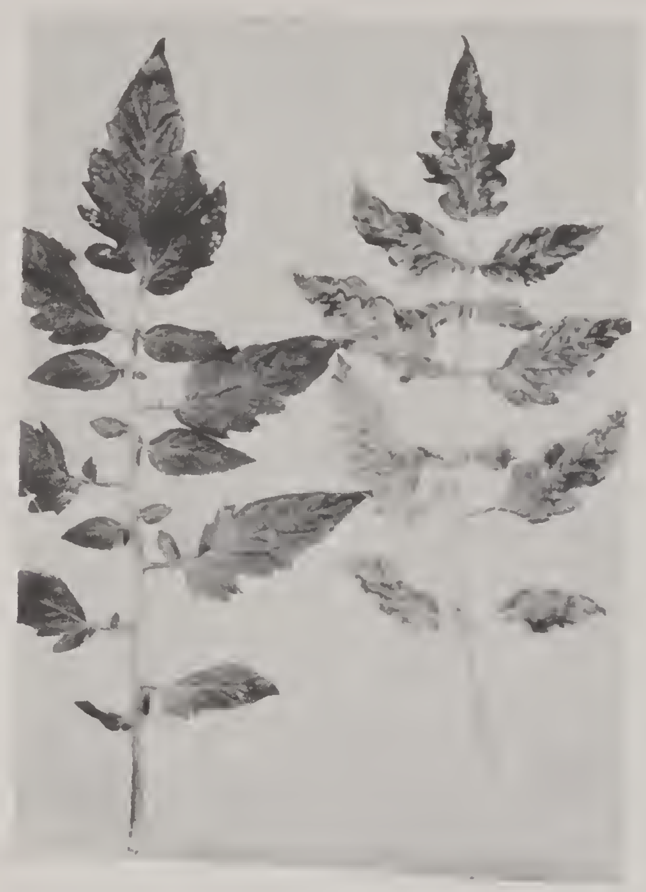


FIG. 113. Tomato mosaic; leaves on left normal.

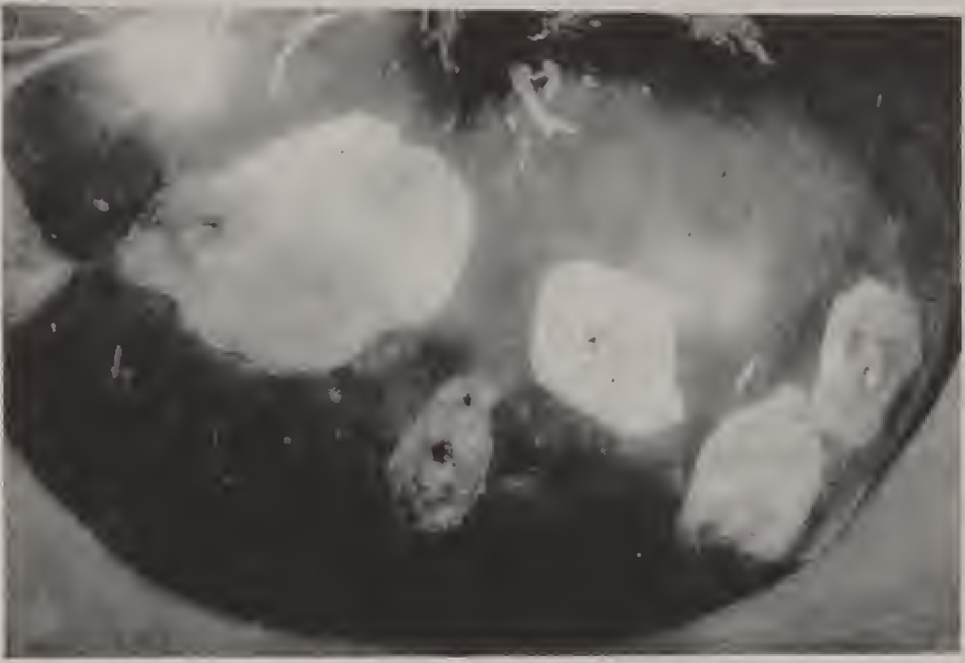


FIG. 114. Russeting on an apple caused by apple red bug injury.

plant or in the soil. Wilting may be permanent, resulting in death, or temporary, with the plants recovering at night.

SCORCH (firing). The sudden death and browning of foliage or sometimes fruit (Fig. 107). Scorches are caused by physical factors such as drought, excessively high temperatures, and injurious chemicals.

BLIGHT. Similar to scorch but is usually applied to foliage or blossoms killed by a disease organism (Fig. 108).

DIE-BACK. The dying backward from the tip of foliage, twigs, or branches of trees and shrubs.

SPOT. A term applied to more or less discolored circular or angular lesions on foliage, fruit, or stems (Fig. 109). Spots are sometimes characterized by target-like banding or zonations of various colors. When the diseased tissues in spots drop out of leaves, leaving circular holes, the term shot-hole is applied.

ROT. Dead tissue in a more or less advanced stage of decay (Fig. 110). It is generally lesional and may appear in woody organs as well as in fleshy ones on all parts of a plant. Thus there may be wood rots, stem rots, bud rots, fruit rots, and root rots. In many fruit rot diseases the final phase is the shriveled-up dry fruit mummies that may remain clinging to the branches.

CANKER. Localized, sharply demarked dead lesions, usually sunken or cracked, in the bark of the trunk, stems, and roots of trees and shrubs or, rarely, on herbaceous plants (Fig. 111). Perennial cankers may show concentric ridges of callus growth.

DAMPING-OFF. The rapid rotting of seeds or seedlings before they emerge from the ground (pre-emergence damping-off) or the rapid rotting of the bases of seedlings so that they fall over (post-emergence damping-off).

BLEEDING. The continuous oozing of sap from wounds or injuries. When this bleeding is accompanied by fermentation

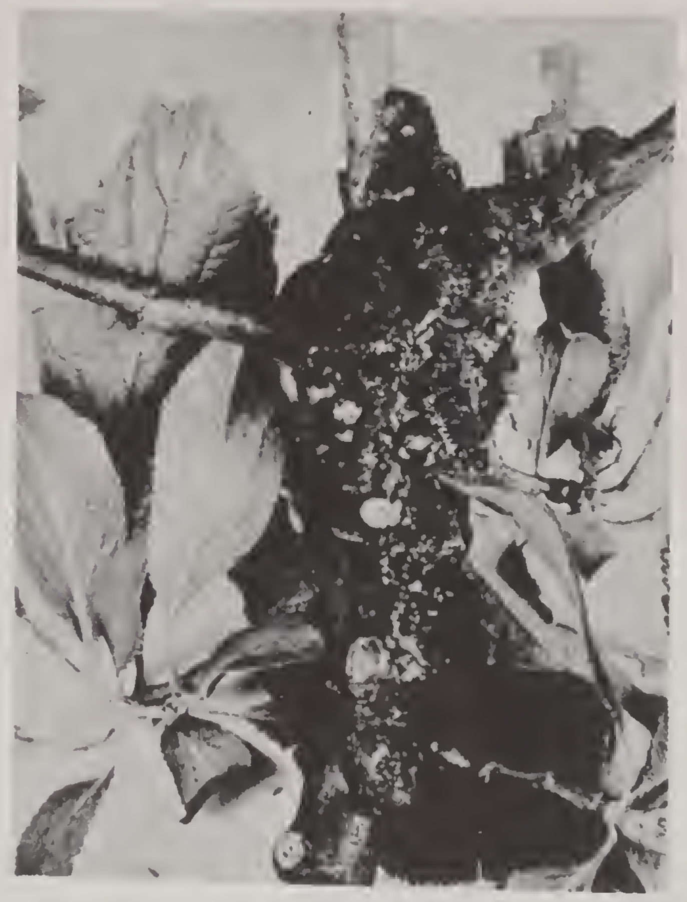


FIG. 115. Black knot on a plum caused by a fungus.

of the sap it is referred to as slime-flux; when it is gummy as on citrus or stone fruits it is called gummosis; and when it occurs in coniferous trees it is called resinosis.

SCALD. The blanching of epidermal tissues that gradually turn pale brown or darken. This symptom commonly occurs on fruits, sometimes on foliage (Fig. 112).

Some Common Hypoplastic Symptoms

ALBICATION. The complete suppression of green color in normally green tissues.

CHLOROSIS. The partial failure of the development of green color in organs that are normally green. Chlorosis may be diffused or patterned. In the diffused type the foliage is light green or yellowish green and is subnormal in size. Patterned chlorosis is characterized by the mottling of leaves.

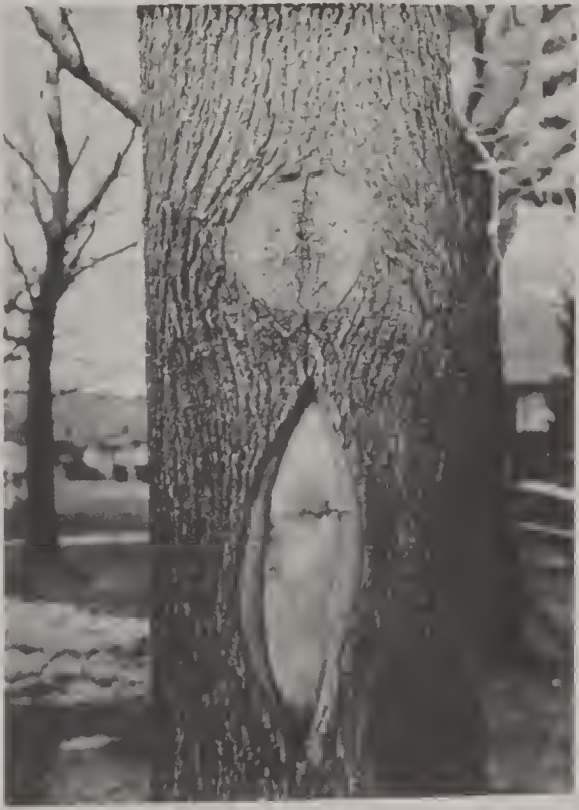


FIG. 116. A wound with callus growth around it. Note also a completely healed wound directly above.

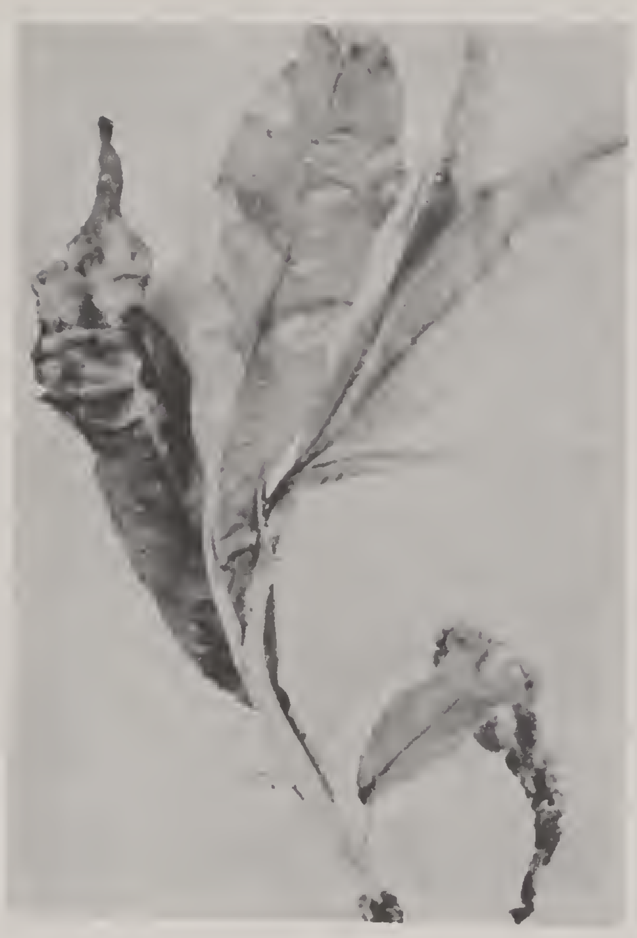


FIG. 117. Peach leaf curl caused by a fungus.

or fruit with definite areas of normal green, light green, and yellow (Fig. 113). Inheritable chlorosis is portrayed by some varieties of arborvitae and a variety of yew in which all or part of the foliage is yellowish.

SUPPRESSION. The failure of certain organs such as flowers or seeds to develop at points where they normally develop.

ETIOLATION. Excessive spindliness accompanied by dwarfing of foliage and flowers and lack of natural chlorophyll development.

DWARFING OR STUNTING. A habital symptom characterized by the subnormal size of the whole plant or of some of

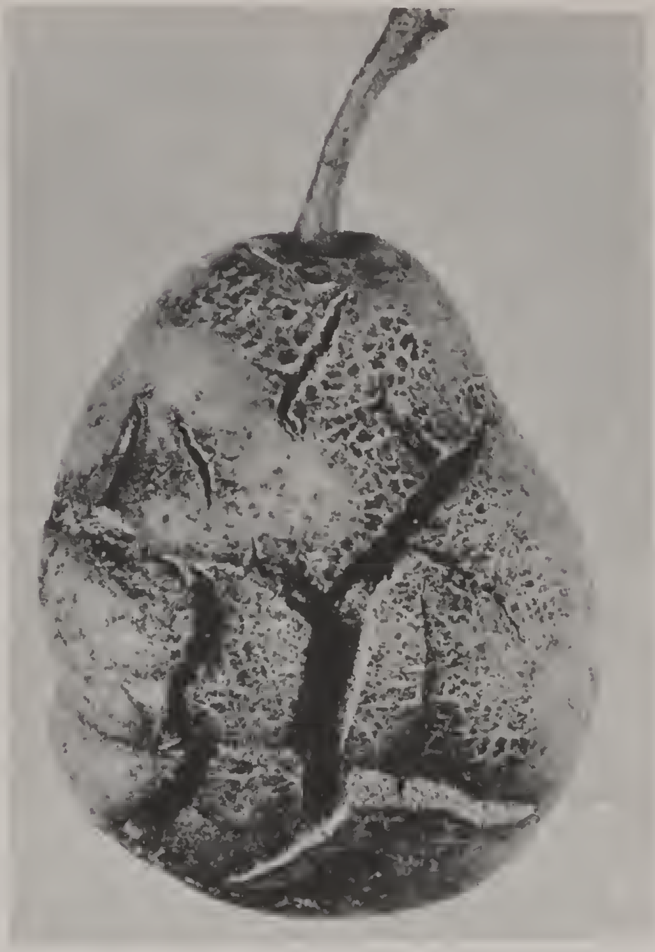


FIG. 118. Pear scab caused by a fungus; the cracking is caused by the scab.

its organs. The symptom may be primary if growth halts in the area of attack or secondary if the whole plant is or if some of its organs are subnormal in growth.

ROSETTING. The crowding of the foliage into a rosette formation caused by the shortening of the internodes of stems or of branches.

Some Hyperplastic Symptoms

PROPLEPSIS. The development of shoots from buds that normally remain dormant. This symptom commonly follows die-back.

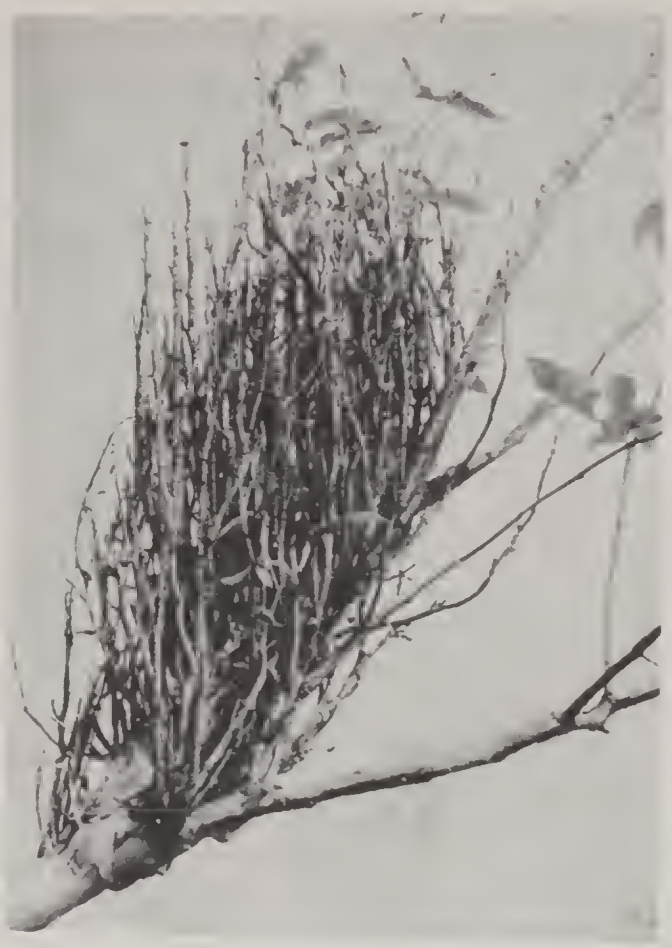


FIG. 119. Witches broom on blueberry caused by a rust fungus.

ABSCISSION OR DEFOLIATION. The premature falling of leaves, flowers, or fruits caused by the formation of the abscission layer at the bases of their petioles. The abscission layer forms normally in the fall of the year, causing fruit and foliage drop from deciduous plants. On evergreens the abscission layer forms on old leaves and needles in the late spring or summer, causing them to drop. Defoliation is a secondary symptom of many diseases.

RUSSETING. The brownish, superficial roughening of the epidermis of fruits, tubers, and other structures (Fig. 114). Injury to the growing epidermis causes suberization and the consequent roughening of the affected areas.

DISCOLORATION. The abnormal coloration of tissues or organs other than yellowing or chlorosis. Discoloration may be lesional or diffused and is frequently a secondary symptom of disease attack. A coppery tinge in the epidermis of green leaves is referred to as bronzing, and a purplish or reddish tinge in green leaves or other plant parts caused by the development of anthocyanin pigments is termed purpling. Purpling may be localized around lesions or may be diffused in the organs as a secondary symptom of injury to roots or branches.

GALLS (tumors). Local swellings or tumor-like growths on any part of a plant (Fig. 115). They may be large or small, smooth or rough, and fleshy or woody. They may bear descriptive names such as warts, knots, tubercles, boils, blisters, and clubs.

CALLUS. New tissue growing over a wound in an attempt to heal it. Callus formation is normal around a pruning wound (Fig. 116), but it often appears around cankered areas as a typical symptom.

CURLING (rolling). The abnormal curling or bending of shoots or leaves because of tissue overgrowth on one side of the affected organ (Fig. 117). Rolling or curling downwards is the first symptom of thirst in leaves.

SCAB. Definite, slightly raised and roughened lesions (sometimes cracked or corky) on fruits, tubers, leaves, or stems (Fig. 118). Scab diseases are lesional.

FASCICULATION. The abnormal development of twigs or roots about a common point. When this occurs on the aerial parts of a plant it is usually called a witches' broom (Fig. 119).

DISEASE PRODUCTS

These are exudates and odors that originate from both the disease-producing organism and from its host or from the disease-producing organism alone. Ooze is the term given to sticky liquid exudates from lesions containing gelatinous-walled bacteria or spores of fungi mixed with the disorganized products of the plant. Ooze usually forms as drops on the surface of lesions as in the case of a fire blight canker (Fig. 120) or as the ooze from the cut stem of a cucumber plant affected with bacterial wilt. Many diseases produce a

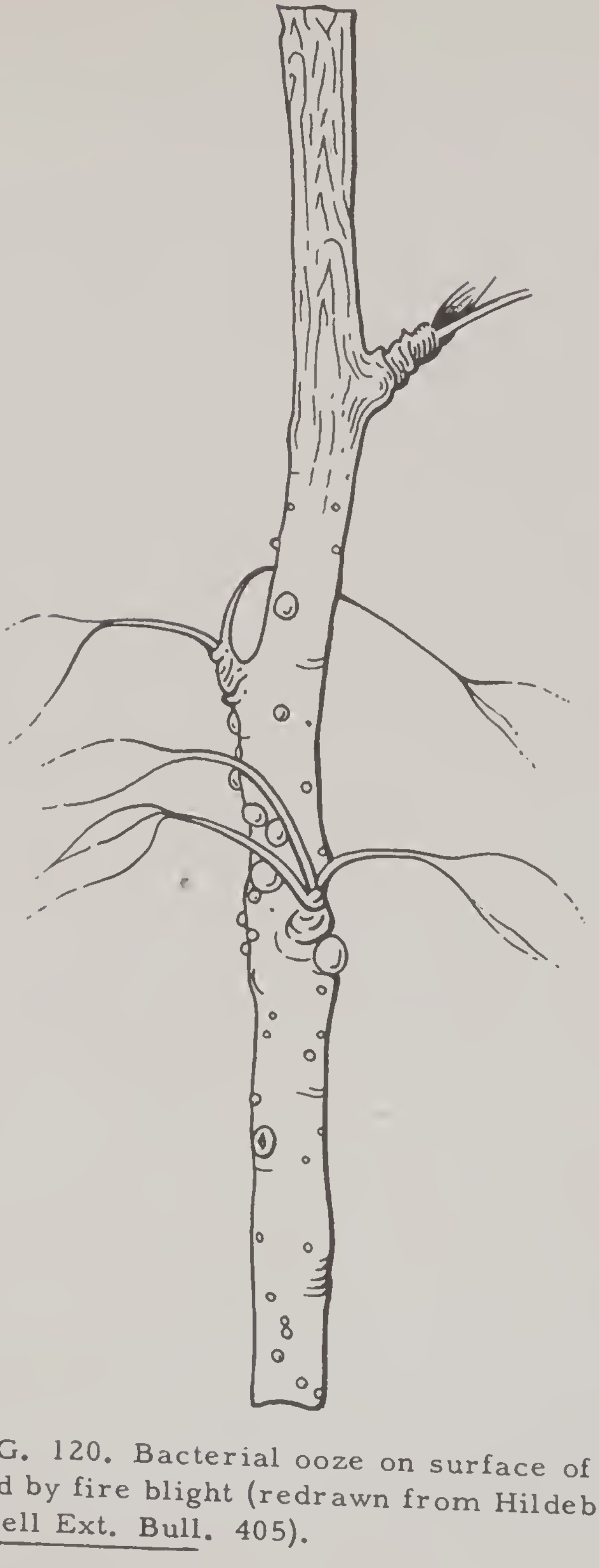


FIG. 120. Bacterial ooze on surface of twig killed by fire blight (redrawn from Hildebrand, Cornell Ext. Bull. 405).

characteristic odor that indicates their presence in the plant or plant part attacked. For example, the late blight of potatoes, the caratovorus soft rot of vegetables, and the orange rust of cane fruits give off characteristic odors.

QUESTIONS FOR DISCUSSION

1. Why is it harder to determine when a plant is diseased than when a person is diseased?
2. Why can most plants be considered diseased to some degree?
3. Is it possible for the layman to mistake a healthy plant for a diseased one? Vice versa?
4. Why must one know what a normal plant of the species looks like during its growth before one can recognize a diseased condition?
5. In what ways does a plant disease resemble a human disease?
6. Are most plant diseases systemic or localized? Human diseases?
7. Do you think growers should be able to diagnose the common diseases of their crops, or should they rely on a plant pathologist?
8. Which is a more reliable basis for disease diagnosis: signs or symptoms?
9. Why is it important to recognize whether a symptom is primary or secondary?
10. Yellow foliage on normally green plants may be either a necrotic symptom or a hypoplastic symptom. What determines the classification?
11. Die-back most often occurs in the late winter and early spring. Why?
12. Can rots occur in plant organs without the presence of bacteria or fungi?
13. Sun-scald cankers usually occur on the southwest sides of trees. Why?
14. Why is defoliation considered a hyperplastic symptom?
15. Why is the curling of shoots considered hyperplastic?
16. Is it necessary to diagnose a disease correctly in order to be able to control it?
17. Are plants able to overcome some of their diseases without human help?

Chapter 14

CAUSES OF PLANT DISEASES

The study of the cause of diseases is generally referred to as etiology (the science of cause). In plant pathology it deals with the primary causal agents or signs of disease in plants and their relation to the suscept or host.

These primary causal agents, generally referred to as pathogenes, fall into three distinct groups: (1) living organisms, (2) viruses, and (3) physiopaths—non-living factors such as improper nutritional and environmental conditions. Viruses and physiopaths are discussed in Chapter 16.

LIVING ORGANISMS CAUSING DISEASE. Diseases caused by living organisms and viruses are usually termed infectious diseases. The attacking organisms are the parasites, and the plants attacked are usually called hosts or suscepts. The living organisms responsible for plant diseases are found mainly in the groups known as bacteria (Schizomycetes), fungi (Eumycetes), and nematode worms (Nemathelminthes) which are discussed in Chapter 5.

In many instances, disease-producing organisms spend part of their life cycle in living tissue and part in dead tissue. Plant pathogenes such as the powdery mildews and the rusts that depend entirely on living plant tissues for food are known as obligate parasites. Some plant pathogenes have become so specialized that they can attack only certain varieties of plant species and are classified as physiological strains or races.

BACTERIA (Schizomycetes)

Bacteria are the cause of many destructive plant diseases such as corn wilt, cucumber wilt, fire blight of pears, soft rot of vegetables, crown gall of fruits, and black spot of delphinium. They are minute, one-celled organisms without chlorophyll but are nevertheless regarded as primitive plants. Although many species were known to be pathogenic to man and to animals, they were not known to cause plant diseases until Burrill discovered about 1879 that fire blight of pears was caused by a member of this group. Since then, nearly 200 bacterial organisms that cause diseases of flowering plants have been found.

CLASSIFICATION OF BACTERIA. Bacteria are grouped into three types—the coccus forms, the bacillus forms, and the spirillum forms. The majority of those that cause plant diseases fall into the bacillus or rod-shaped group (Fig. 121), family Bactereaceae, genera *Erwinia* and *Pseudomonas*. A few plant-pathogenic bacteria belong to the higher genus *Actinomyces*; the most important is *A. scabies*, the cause of cause of common scab of potato. The system of naming bacteria has undergone several changes in the past, and as a result the same organism may be known by two or more scientific names.

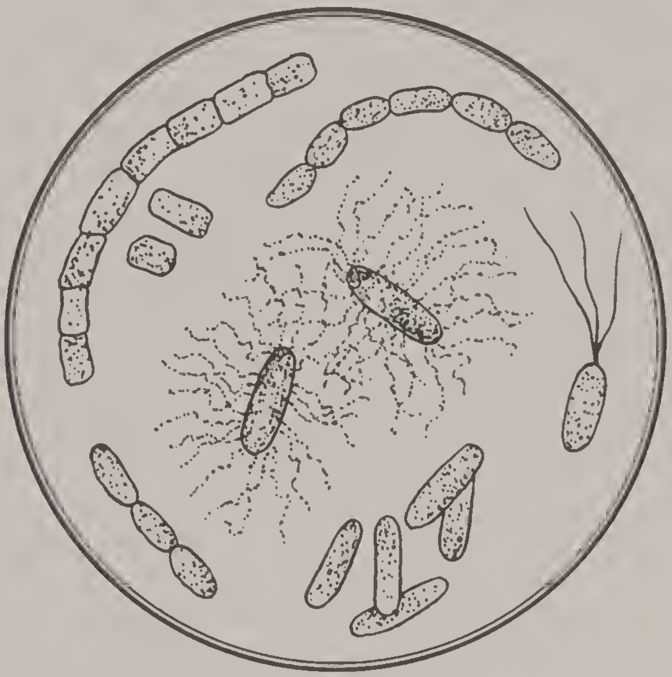


FIG. 121. Bacillus types of bacteria (from various sources).

None of the plant-pathogenic bacteria are known to form spores; they multiply rapidly in host tissue by simple division. They are usually Gram-negative; that is, they do not take on the standard Gram's stain. They are generally white or yellow, motile, with flagella; and aerobic. Some are obligate parasites; that is, they depend on continuous association with living tissues of their hosts for existence; others may live for various lengths of time as saprophytes on dead plant tissues, in the soil, or in culture media. They are favored by high temperatures.

MODE OF ATTACK. Succulent plant tissues are most susceptible to bacterial attack. Some bacteria can enter only through wounds or lesions made by natural forces or by insects or other animals; others may gain entrance through water pores, stomata, lenticels, and in a few cases the nectaries of flowers. Bacteria cannot enter directly through the epidermis. Once inside the host's tissue they multiply and migrate from cell to cell or between cells.

DISSEMINATION. Bacterial disease organisms may survive from year to year in plant parts, soil, or the intestines of insects. They may be spread or disseminated by insects, splashing rain drops, dripping dew, running water, animals, tools, plant parts, or infected seed. Symptoms of a bacterial disease may not differ greatly from those of other diseases, and therefore accurate diagnosis may require that the causal organism be found in the lesion or in the ooze that may form on or in the affected tissues.

PATHOLOGICAL EFFECTS. Bacteria may harm plants by secreting enzymes that destroy cells, by secreting toxic substances that poison and kill host cells, or by producing hormones that lead to cancerous cell development. Bacterial diseases may produce three types of disease symptoms in plants: (1) localized or generalized killing of tissues, as found in blights, spots, and rots; (2) invasion and spread through the vascular tissues, producing wilts; and (3) excessive multiplication of host cells, producing galls.

TABLE 23

SOME IMPORTANT BACTERIAL DISEASES OF PLANTS

Disease	Cause	Hosts
Bacterial gummosis	*Pseudomonas cerasus*	Stone fruits
	P. vascularum	Sugarcane
Black spot	*P. delphinii*	Larkspur or delphinium
Black rot	*P. campestris*	Crucifers
Blight	*P. phaesoli*	Beans
	P. pisi	Peas

Table 23 (Continued)

Disease	Cause	Host
Blight	*P. translucens*	Barley
	P. syringae	Lilac
	P. juglandis	Walnut
Crown gall	*P. tumefaciens*	Fruits, shrubs, trees
Angular leaf spot	*P. lachrymans*	Cucumber
Leaf spot	*P. trifoliorum*	Clover
	P. erodii	Geranium
Fire blight	*Erwinia amylovorus*	Apple, pear, etc.
Soft rot	*E. carotovorus*	Root vegetables
Wilt	*E. tracheiphilus*	Cucurbits
	P. malvacearum	Cotton
	P. angulata	Tobacco
	P. stewarti	Sweet corn
	P. insidiosum	Alfalfa
Potato scab	*Actinomyces scabies*	Potato

THE FUNGI

Fungi are primitive plants, but they lack chlorophyll and must therefore obtain their food from animals or plants. There are thousands of species of fungi with seemingly endless adaptations and diversifications. Most are harmless saprophytes competing with and destroying harmful organisms, feeding on dead animal or plant remains, and helping to break down organic matter. Some are used for making cheese and for producing mushrooms for human consumption; others parasitize insects. A few cause diseases of man, such as "athletes foot" and "ringworm." Many fungi invade higher plants for feeding purposes, and these produce the majority of infectious plant diseases. During their life, fungi like other plants first produce vegetative structures, which may later give rise to reproductive structures.

Vegetative Structures of Fungi

The body of a fungus consists of delicate tubular, cottony filaments known as *hyphae* (singular, *hypha*), which form branched systems of threads called *mycelia* (Fig. 122). When

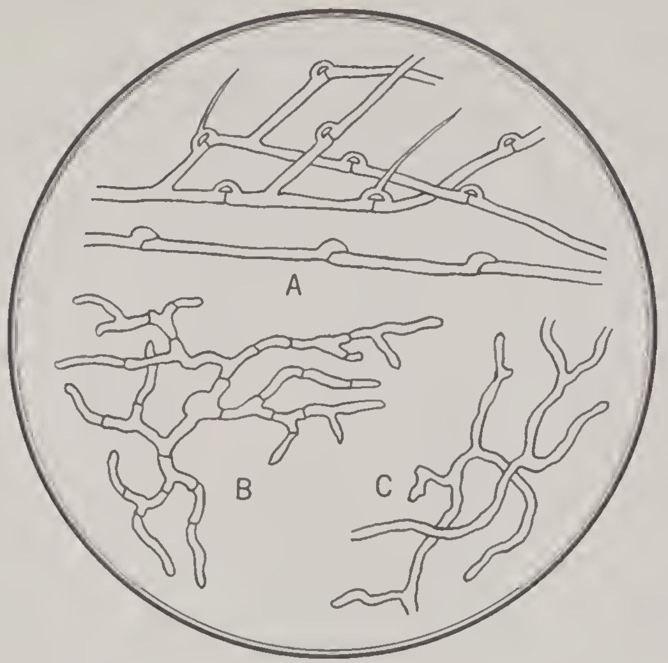


FIG. 122. The mycelia of fungi. A, Basidiomycetes type of mycelium showing clamp connections; B, Ascomycetes type of mycelium showing its septate character; C, Phycomycetes type of mycelium showing its non-septate character (from various sources).

the mycelium forms as a dense or loose, woolly mat or web, it is usually referred to as a felt. Hyphae are generally white but may be red, black, brown, yellow, olive, or greenish. Aerial hyphae such as those found in the powdery mildews send specialized absorbing organs, haustoria, into the cells. Intercellular hyphae such as those found in the rusts may also send haustoria into the cells to obtain nourishment.

The mycelia of fungi may exhibit different branching habits and structure, which help in identification and diagnosis. When a mycelium begins to grow, it generally radiates from its point of origin and therefore tends to produce round lesions, characteristic of many fungous diseases.

Some fungi excrete toxic substances into the surrounding tissues, destroying them, and then live on the dead tissues as saprophytes; others feed directly on living cells, absorbing the cellular food through the hyphal walls or through the haustoria.

The Reproductive Structures of Fungi

Fungi commonly disseminate and reproduce themselves by means of tiny, microscopic bodies called spores (Fig. 123),

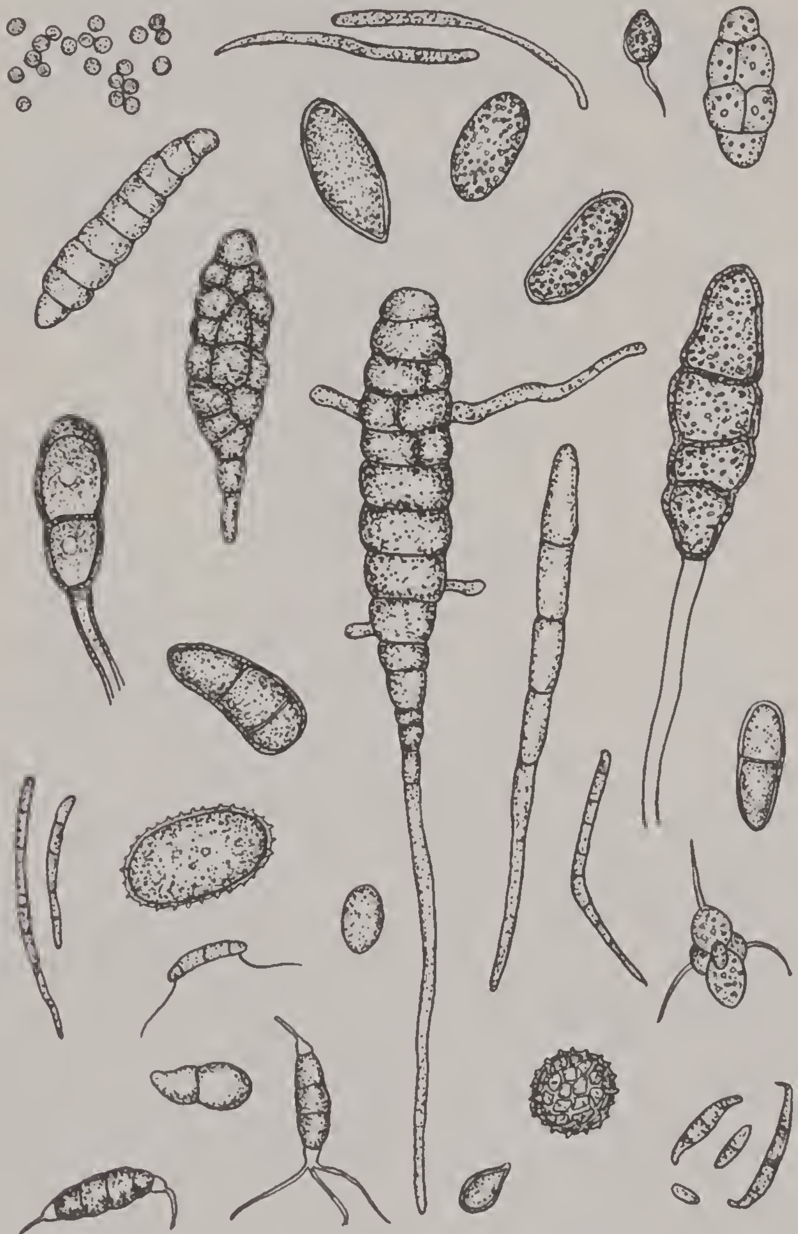


FIG. 123. The spores of fungi showing the great variations in their structure, all greatly magnified (redrawn from Schwarze, N. J. Agr. Expt. Sta. Bull. 313).

which function like the seeds of higher plants. A spore landing on the appropriate part of a suscept under proper moisture and temperature conditions is capable of producing a new fungous body. These spores are named in accordance with the way in which they originate. If they are produced either by budding or by breaking off from the tips of specialized hyphae, they are called *conidia* and the hyphae are called *conidiophores* (Fig. 124). If the spores are produced within

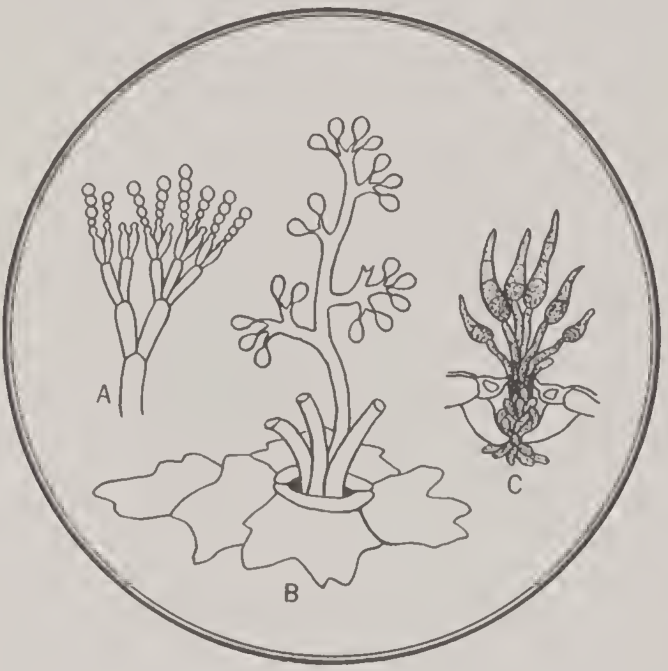


FIG. 124. Conidiophores. A, blue mold or *Penicillium*; B, downy mildew (*Peronospora*); C, *Cercospora* (redrawn from Heald, *Manual of Plant Diseases*).

or on the outside of structures known as spore fruits or fruiting bodies, they are given names depending on the type of fruiting body from which they originate. Spores of different fungous species vary greatly in size, shape, color, and origin. Often their presence on or in a lesion can be used as a diagnostic sign of disease. Spores vary in size from 1 micron to 1 millimeter, but generally, unless seen in aggregate masses, they are not distinguishable by the naked eye.

TYPES OF SPORES. Spores may be motile or non-motile, and sexual or asexual. The same fungus may produce several types of spores during its seasonal cycle. Most fungi produce two or three types of spores, but some, like the rusts, may have as many as five types. Spores are usually produced on the surface of infected tissues, but sometimes spores form within plant tissues. Spores may be one-celled, two-celled or several-celled. They are produced sexually as the result of the fusion of two similar or dissimilar cells (Fig. 125) or asexually. When spores are motile they are usually called swarm spores or zoöspores (Fig. 126). In all downy mildews except species of Peronospora, swarm spores are produced. They swim around for a brief period, encyst, then germinate by the production of a germ tube.

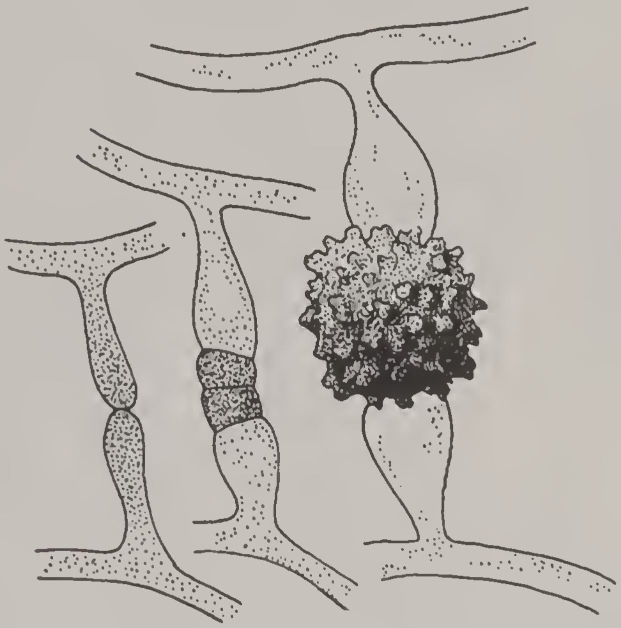


FIG. 125. Stages in the development of a sexual spore (zygospore) as the result of the union of two similar cells (gametes).

Special resting or resistant spores that favor survival of the fungus are called chlamydospores when formed simply as enlarged, thick-walled hyphal cells. They may occur singly or in groups in the hyphae.

Spores may be disseminated by air currents, splashing rain, running water, animals, tools, and man.

The fruiting bodies that bear the spores are discussed under the different groups of fungi of which they are characteristic.

On the basis of mycelial type and of method of reproduction, fungi may be divided into four important classes: (1) Phycomycetes, (2) Ascomycetes, (3) Basidiomycetes, and (4) Fungi Imperfecti.

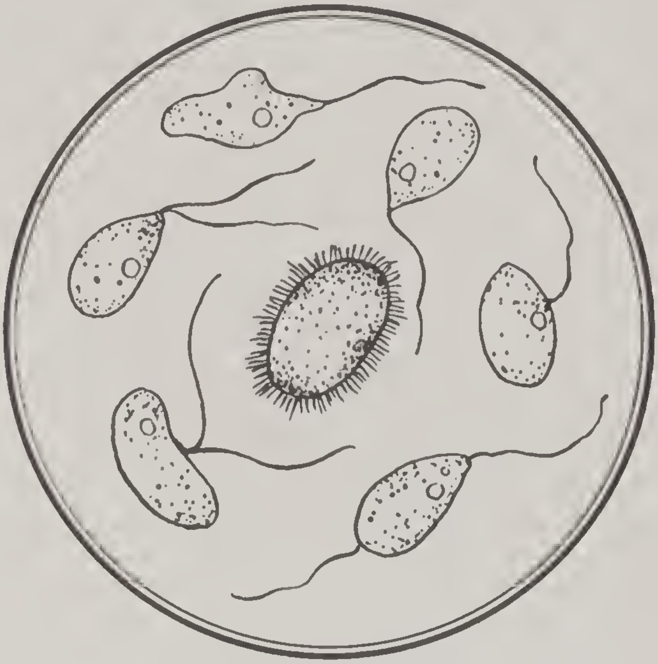


FIG. 126. Types of swarmspores or zoöspores.

The Phycomycetes

The Phycomycetes include many forms that are pathogenic to higher plants. Generally, the mycelium is multinucleate, single-branched, and lacking in cross walls (non-septate) except those that set off the reproductive organs (Fig. 122C). Septations sometimes occur in young hyphae or in old hyphae in the process of forming chlamydospores.

Asexual reproduction in most Phycomycetes takes place through the production of sporangia (Fig. 127) that bear either simple, air-borne spores or motile, water-borne swarm spores (zoöspores). Conidia may be produced in some cases.

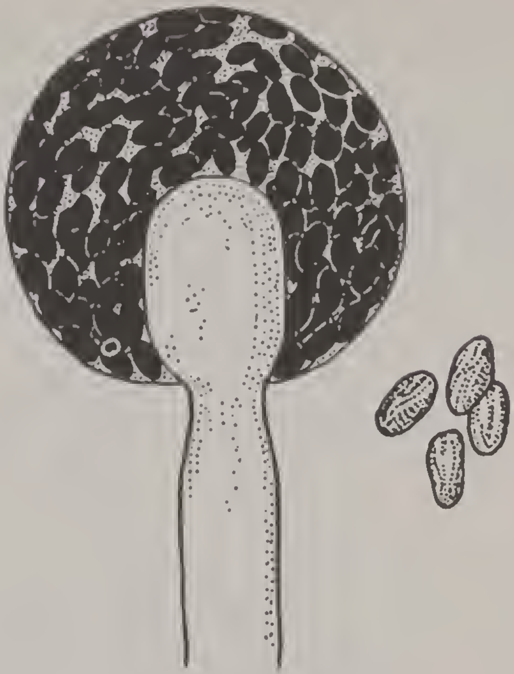


FIG. 127. A sporangium of the bread mold fungus.

Sexual reproduction, when present, is either by the union of the two unequal sex cells or gametes to form an *oöspore* or by the union of two equal sex cells or gametes to form a *zygospore* (Fig. 125).

TABLE 24

SOME OF THE MOST IMPORTANT DISEASES CAUSED BY PHYCOMYCETES

Common Name of Disease	Causal Organism	Host Plants
Clubroot	*Plasmodiophora brassicae*	Crucifers
Damping-off	*Pythium debaryanum* and other species	Numerous species
Late blight	*Phytophthora infestans*	Potato, tomato
Downy mildew	*Phytophthora phaseoli*	Lima bean
White rust	*Albugo candida* and other species	Crucifers, *Compositae*, sweet potato

Table 24 (Continued)

Common Name of Disease	Causal Organism	Host Plants
Downy mildew	Sclerospora, Plasmopara, and Peronospora spp.	Grains, grasses, grapes, cucurbits, crucifers, roses, tobacco, etc.
Soft rot, leak, vegetable rot	Rhizopus nigricans and other species	Sweet potato, various vegetables and fruits

The Ascomycetes (Sac Fungi)

The higher Ascomycetes all have the common characteristics of a septate mycelium and of forming sexual spores (ascospores) in a specialized sac-like cell or ascus. They have no motile spore forms.

VEGETATIVE STRUCTURES. The hyphae are generally septate and composed of uninucleate cells (Fig. 122B). Haustoria are present in those forms known as powdery mildews and sooty molds. Some hyphal cells may separate with age and form conidia, or they may become thick-walled and form chlamydospores. In some Ascomycetes the mycelium may aggregate into compact masses called sclerotia or stromata (Figs. 128 and 129). In this stage the fungus is able to survive long periods of unfavorable conditions. In some obligate species the hyphae overwinter within twigs or buds, and the mycelium is perennial.

ASEXUAL OR IMPERFECT STAGE. The majority of Ascomycetes have one or more asexual or conidial stages. The conidia of the asexual stage vary greatly, depending on the species. They are one-, two-, or many-celled and are borne free on the ends of conidiophores or in fruiting bodies which, according to their structure, are called acervuli, pycnidia, or sporodochia (Figs. 130, 131 and 132). In some cases conidia are able to survive from year to year in these fruiting bodies.

SEXUAL OR PERFECT STAGE. The characteristic asci may develop singly or in groups in a palisade-like layer on the surface of the affected tissue, as in the leaf-curl fungi;

or they may be grouped into definite fruiting bodies or ascocarps known as *perithecia* (Fig. 133) (sphere fungi or Pyrenomycetes), *apothecia* (Fig. 134) (disc or cup fungi, Discomycetes), or *cleistothecia* (Fig. 135) (powdery mildews and sooty molds). A few Ascomycetes produce only ascospores, but most produce one or more forms of conidial fruits.

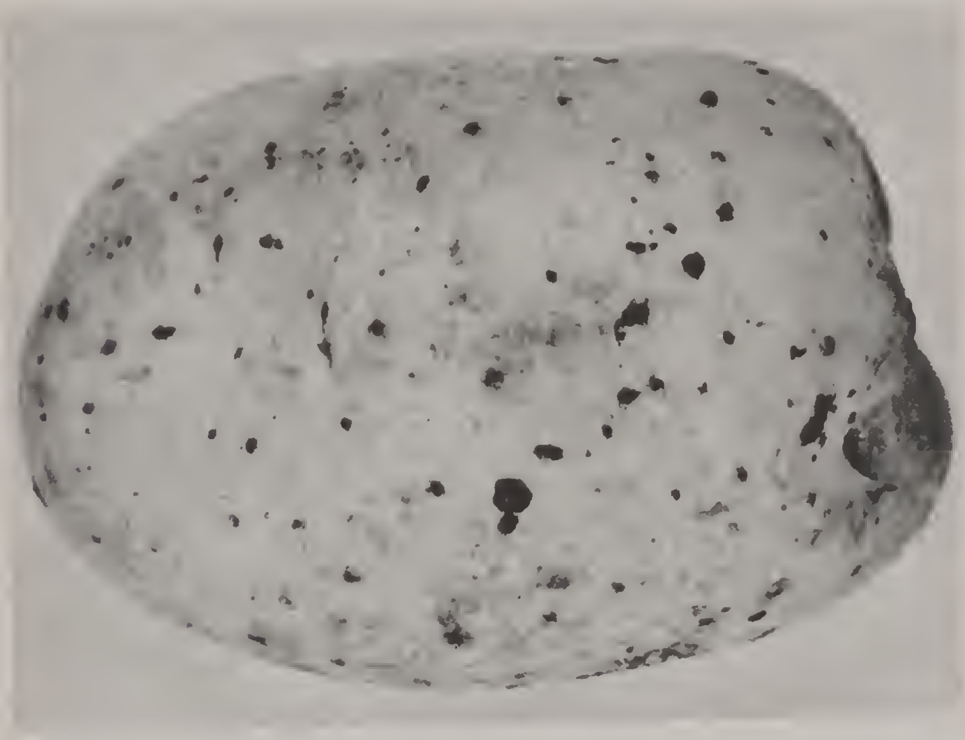


FIG. 128. Sclerotia of *Rhizoctonia* on a potato.

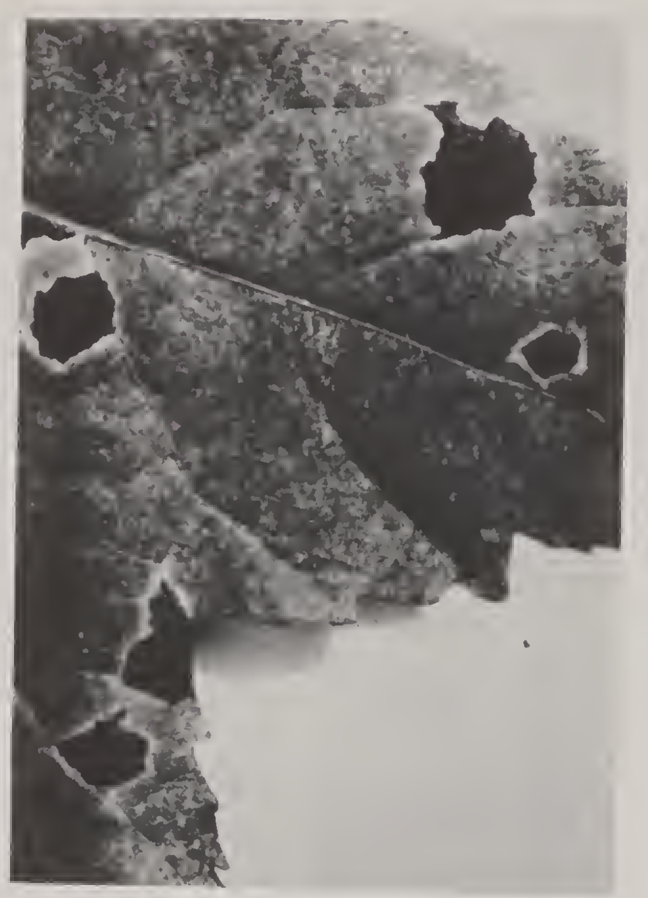


FIG. 129. Tar spot of maple showing black, flattened stromata.

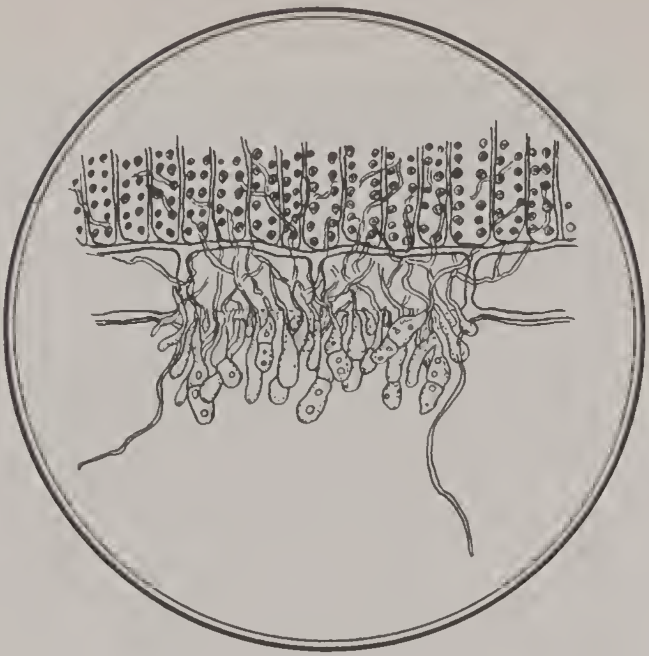


FIG. 130. Cross section through an acervulus, greatly enlarged (redrawn from Schwarze, N. J. Agr. Expt. Sta. Bull. 313).

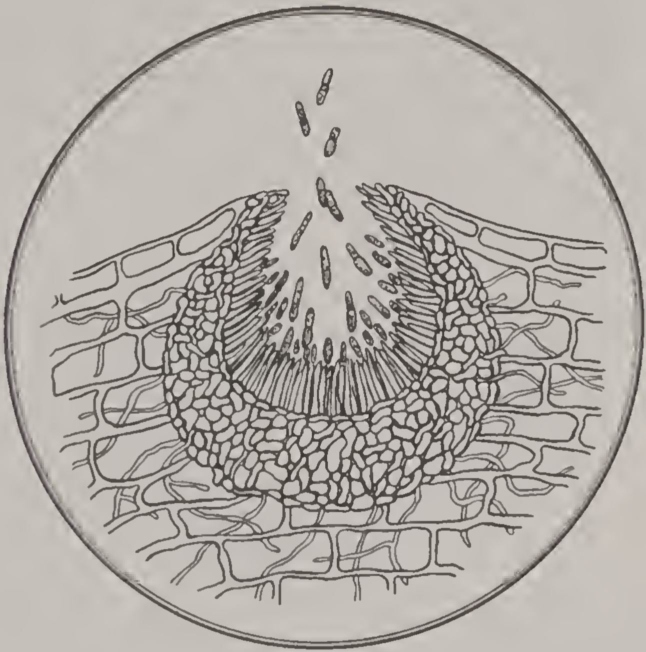


FIG. 131. Cross section through a pycnidium, greatly enlarged (redrawn from Schwarze, N. J. Agr. Expt. Sta. Bull. 313).

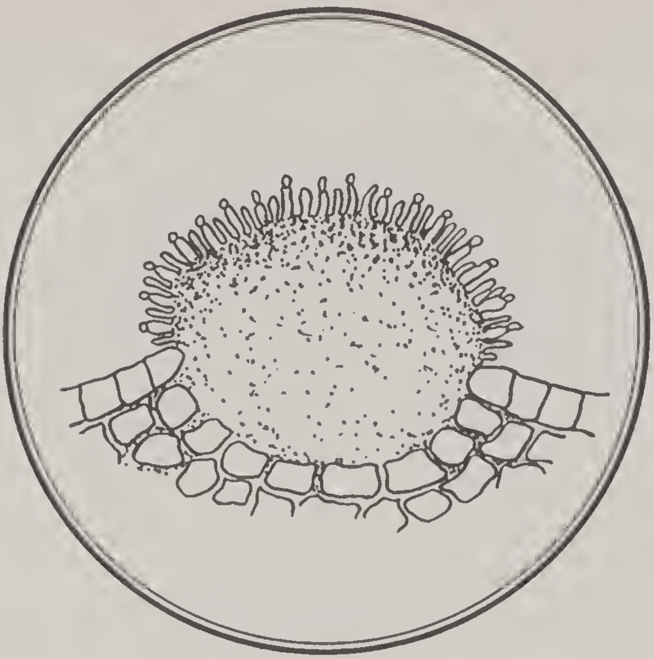


FIG. 132. A sporodochium (redrawn from Heald, Manual of Plant Diseases).

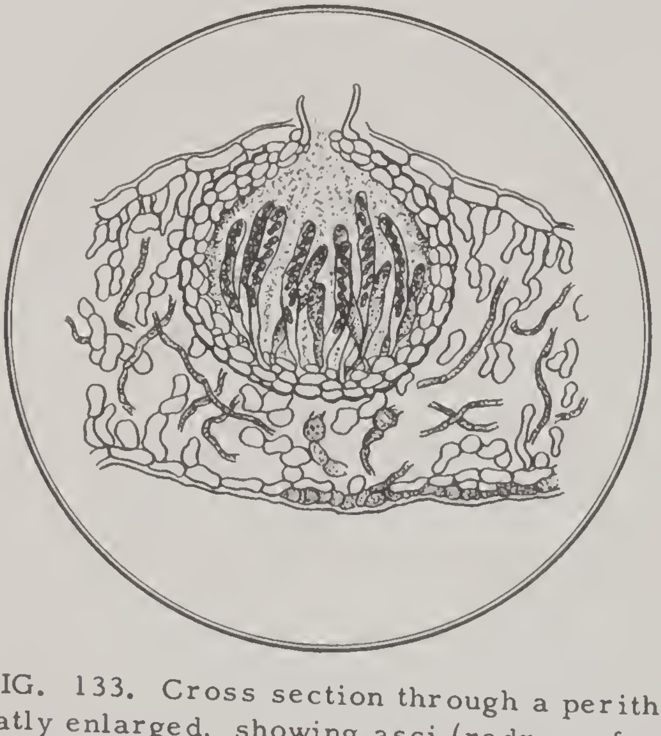


FIG. 133. Cross section through a perithecium, greatly enlarged, showing asci (redrawn from Melhus and Kent, Elements of Plant Pathology).

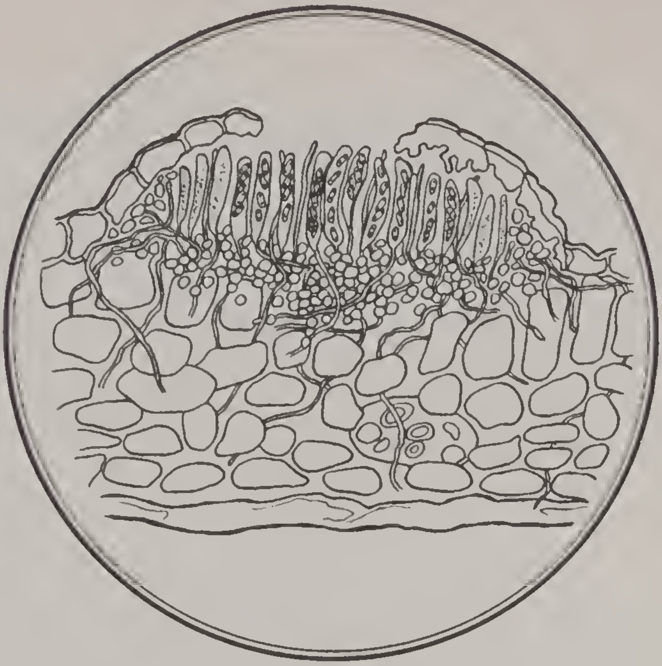


FIG. 134. Cross section through an apothecium, greatly enlarged (redrawn from Heald, Manual of Plant Diseases).

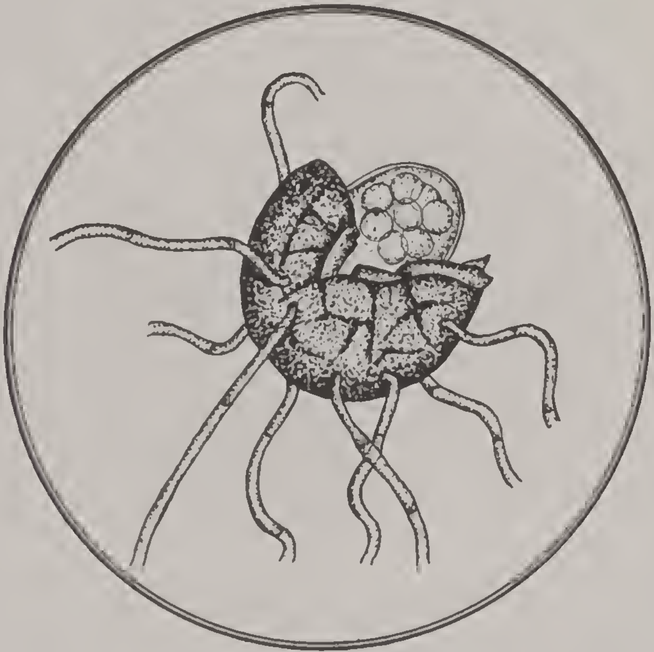


FIG. 135. A cleistothecium, greatly enlarged (redrawn from Schwarze, N. J. Agr. Expt. Sta. Bull. 313).

TABLE 25

SOME IMPORTANT DISEASES CAUSED BY ASCOMYCETES

Disease	Causal Organism	Host
Leaf curl, leaf blister	Taphrina spp.	Peach, pear, oak, cherry
Brown rot	Sclerotinia spp.	Stone fruits, pome fruits
Anthracnose	Pseudopeziza ribis	Currants, gooseberries
Anthracnose	Glomerella gossypii	Cotton
Powdery mildew	Sphaerotheca spp.	Rose, strawberry, peach, gooseberry
	Erysiphe spp.	Pea clover, cereals, grasses, cucurbits, composites, etc.
	Podosphaera spp.	Apple, pear, quince, cherry, etc.
Black spot	Diplocarpon rosae	Rose
Canker	Nectria spp.	Apple, pear, boxwood, many other deciduous trees and shrubs
Root, stalk, and ear rot, seedling blight	Gibberella saubinetii	Corn, small grains
Ergot	Claviceps purpurea	Rye and other cereals
Black knot	Dibotryon spp.	Plum, cherry, currant, gooseberry
Bitter rot	Glomerella cingulata	Apple, pear, quince, grape
Endothia canker or blight	Endothia parasitica	Chestnut
Black rot	Guignardia bidwellii	Grape
Leaf spot	Mycosphaerella spp.	Strawberry, Rubus spp., currants, gooseberries, peas, beets
Scab	Venturia spp.	Apple, pear, poplar

The Basidiomycetes

These include the rust, smut, and palisade fungi. They are characterized by a septate mycelium, often with "clamp connections" (Fig. 122A) and by a typically club-shaped, non-

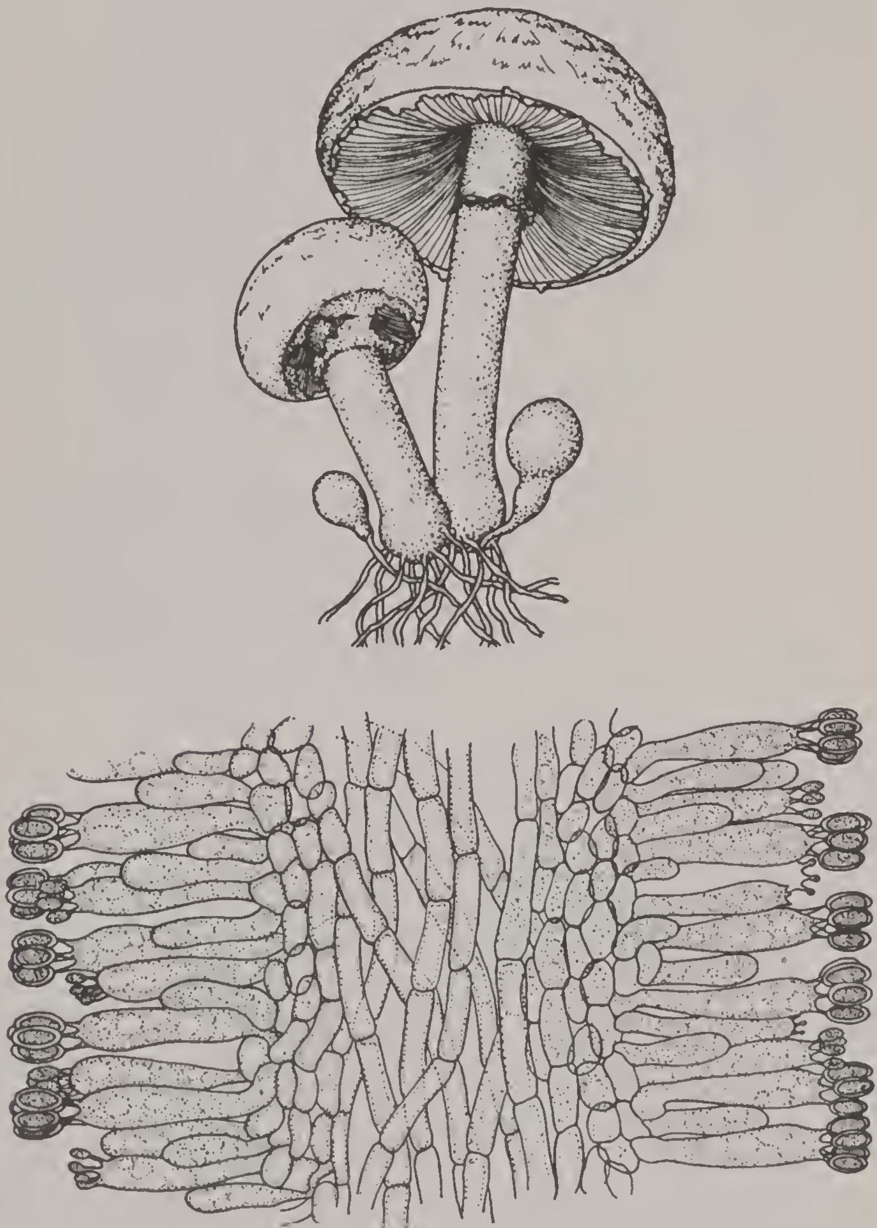


FIG. 136. Toadstools, with enlarged drawings of basidia and basidiospores.

segmented basidium on which the spores (basidiospores, usually four) are formed (Fig. 136).

VEGETATIVE STRUCTURES. The conspicuous parts of most species of Basidiomycetes are the fruiting bodies (basidiocarps or sporophores) and the spores, but the actual body of the fungus is the inconspicuous mycelium usually well hidden in the organic matter or in the host's tissues. The mycelium is usually present as felts or wefts of hyphae, as delicate mycelial strands, or as thickened, interlacing strands of mycelium called rhizomorphs (Fig. 137). The mycelium of parasitic species is intercellular—the rusts have haustoria for penetrating into cells.

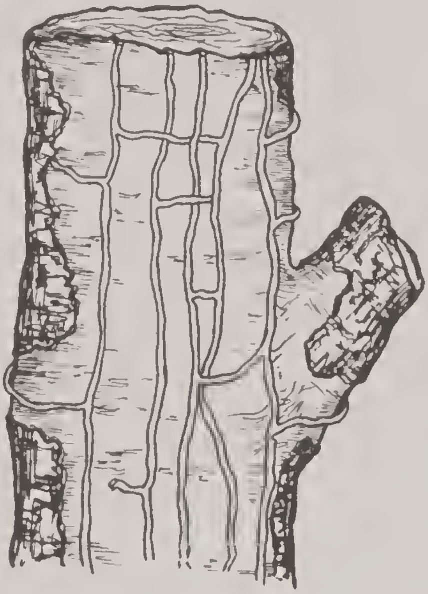


FIG. 137. Rhizomorphs under the bark of a tree.

THE SMUTS (Ustilaginales). The smuts are obligate parasites that are responsible for enormous losses of cereals. Specific smut-producing fungi generally attack only one organ, but any organ above ground may be attacked by smuts. The smut spores or chlamydospores typically have thickened walls, are smooth or sculptured, and are usually black, brown, or violet. The black spore masses formed by the smuts either break up into a dust-like powder easily blown by the wind (loose smuts) or remain in place more or less covered (kernel or covered smuts).

Some smut spores may germinate only after a period of dormancy; others may germinate immediately after maturity. They may retain their vitality for several years. In germination they produce a basidium (promycelium) with primary or secondary sporidia (basidiospores) or in some cases many-branched hyphae (Fig. 138). The sporidia may infect seedlings before they emerge from the soil, as in oat smut and wheat bunt; they may infect any embryonic tissues, resulting in local lesions in various organs, as in corn smut; or they may infect the ovary through the stigma of the flower and remain as dormant mycelium in the seed until it germinates, when infection becomes systemic, as in loose smut of wheat and naked smut of barley. Sporulation occurs when the host flowers. Smut spores will germinate readily in the compost pile, and the sporidia will continue to bud (like yeast cells) under these conditions until enormous numbers of spores have been produced.

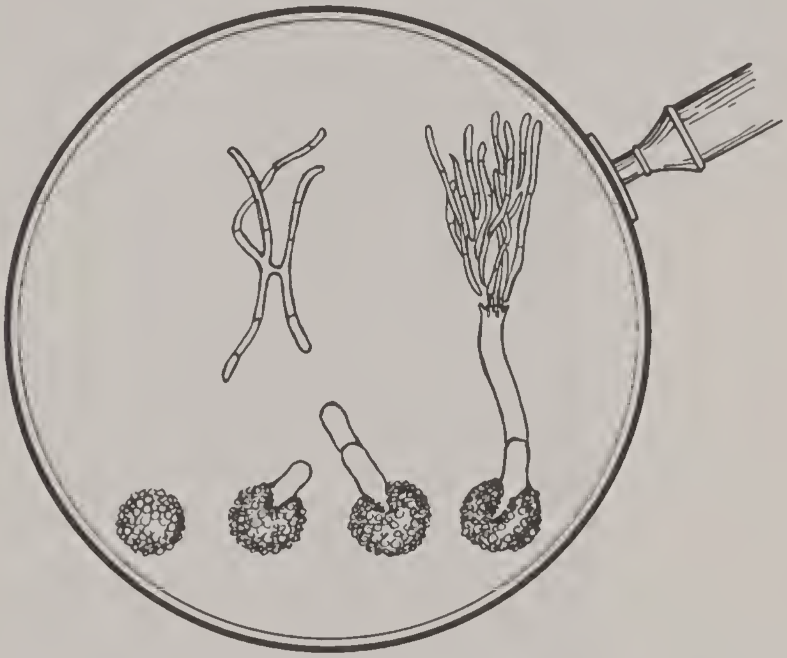


FIG. 138. The germination of a smut spore showing the formation of the basidium bearing basidiospores (sporidia).

TABLE 26

SOME IMPORTANT DISEASES CAUSED BY SMUT FUNGI

Disease	Causal Organism	Host
Loose smut	*Ustilago avenae*	Oats
	Ustilago tritici	Wheat, rye
	Ustilago nuda	Barley
Covered or kernel smut	*Ustilago levis*	Oats
	Ustilago hordei	Barley
	Ustilago fischeri	Corn
	Ustilago cruenta	Sorghum
Boil or common smut	*Ustilago zeae*	Corn
Bunt or stinking smut	*Tilletia tritici*	Wheat
	Tilletia levis	Wheat
Black smut	*Tilletia horrida*	Rice
Onion smut	*Urocystis cepulae*	Onion
White smut	*Entyloma* spp.	Spinach, dahlia, sunflower

THE RUST FUNGI (*Uridinales*). Rusts are obligate parasites. The name of the order is derived from the rusty spore pustules or *sori* that are typical of certain stages. Rusts have been mentioned in connection with plants ever since their cultivation began. They are responsible for great crop losses. The life histories of some rusts are very complex and in some cases are not completely known or understood.

Vegetative Structures. The mycelium of rusts is generally intercellular, branched, and septate, with haustoria present. Yellowish or orange-red drops of oil may be observed in the mycelium. The mycelium may be annual or perennial depending on the rust species and on the suscept.

Reproductive Structures. One of the striking features of rusts is their different spore forms (*polymorphism*). Many rusts may produce as many as five different spore forms in the course of their complete life cycle. Another peculiar characteristic of rusts is the necessity in many species for two unrelated hosts to complete their developmental cycle. Such rusts are termed *heteroecious* (as opposed to *autoecious*), with certain spore forms developing on one host and the other spore forms on the wholly unrelated species.

Spore Forms. The five spore fruits and spore forms in the typical life cycle of a heteroecious rust are listed in Table 27 and are shown in Fig. 139, but in some species one or more stages in the developmental cycle are regularly missing.

TABLE 27

SPORE FRUITS AND SPORES OF RUSTS

Symbol	Spore Fruits	Spores
0	Pycnia	Pycniospores (spermatia)
I	Aecia	Aeciospores
II	Uredinia (sori)	Urediniospores
III	Telia (sori)	Teliospores
IV	Basidia (promycelia)	Basidiospores (sporidia)

If pycnia (0) and aecia (I) are on the same host as telia (III) the rust is autoecious; and if (0) and (I) are on different species than (III) is on the rust is heteroecious.

The existence of specialized races among rusts, especially those of cereals, is more common than among powdery mildews. Some rust races may be very virulent and may attack a wide number of varieties of a species, whereas others may produce disease in one variety only. For example, Puccinia graminis tritici which attacks wheat, barley, and wild grasses has more than 180 known physiological races specific on certain varieties only.

TABLE 28

SOME IMPORTANT RUST DISEASES

Disease	Causal Organism	Host
Stem rust	Puccinia graminis tritici	Wheat, grasses (alt. host, barberry)
	Puccinia graminis avenae	Oat, grasses (alt. host, barberry)
	Puccinia graminis secalis	Rye, grasses (alt. host, barberry)

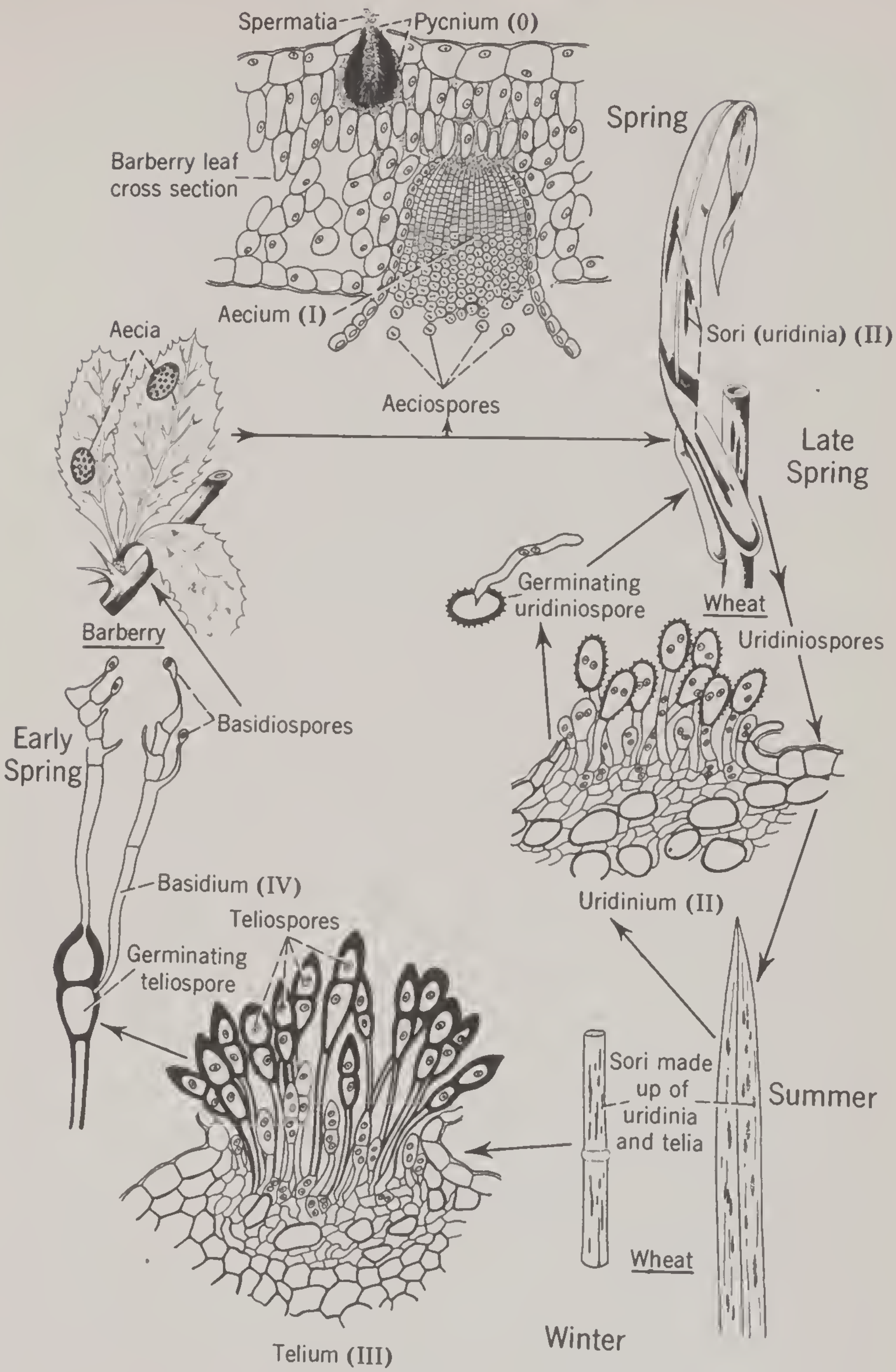


FIG. 139. The life cycle of the stem rust of wheat.

Table 28 (Continued)

Disease	Causal Organism	Host
Leaf rust of wheat	Puccinia triticina	Wheat (alt. host?)
Stripe rust of wheat and rye	Puccinia glumarum	Wheat, rye, grasses (alt. host?)
Crown rust of oats	Puccinia coronata	Oats, grasses (alt. host, buckthorn)
Cedar-apple rust	Gymnosporangium juniperi-virginianae	Apples (alt. host, red cedar)
Blister rust	Cronartium ribicola	Five-needled pines (alt. host, currants and gooseberries)
Asparagus rust	Puccinia asparagi	Asparagus
Bean rust	Uromyces phaesoli	Beans and Lima beans
Carnation rust	Uromyces caryophyllinus	Carnations
Hollyhock rust	Puccinia malvacearum	Hollyhocks, common mallow

THE PALISADE FUNGI (Homobasidiomycetes). These fungi get their name from the palisade-like arrangement of the basidia. This group is of great importance in relation to diseases of growing trees and in the decays of logs and lumber (Fig. 140). A few may attack herbaceous plants. The distinguishing feature of most of this group is the large fruiting bodies, which are often mistaken for the fungous body itself. The fungus is concealed in the host and undergoes considerable growth before it produces the conspicuous fruiting bodies (sporocarps or basidiocarps, Fig. 141).

The Mycelium. The most distinguishing characteristics of the mycelium of this group are its clamp-like connections, where the septations occur, and the binucleate condition of the hyphal cells. The presence of these clamp connections is often a convenient sign for recognizing a fungus of this group (Fig. 122A).

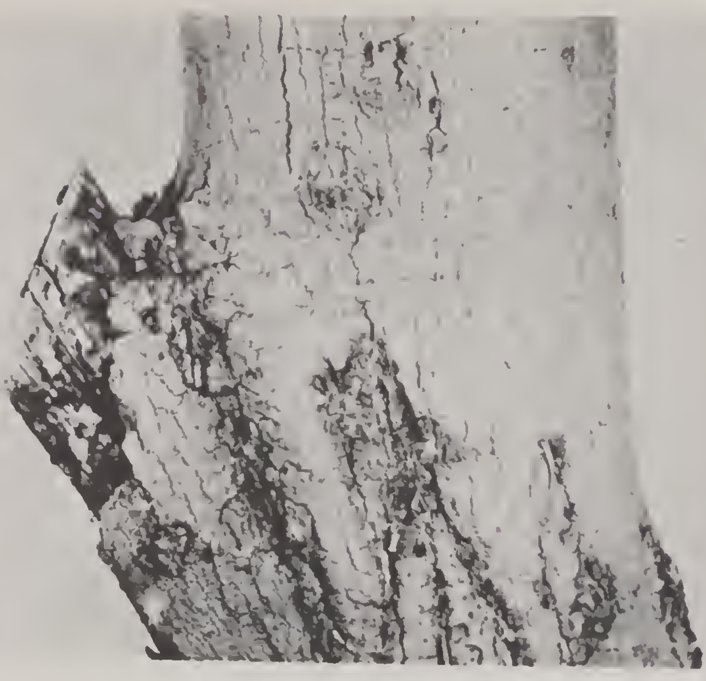


FIG. 140. A rot in a maple caused by a poor and unprotected pruning cut.

Reproductive Structures. Basidia are formed from club-shaped hyphae that usually bear four basidiospores, but the number may vary from two to eight. These basidia are arranged side-by-side in a layer and arise in various fleshy, corky, or woody structures known as toadstools (Fig. 136), mushrooms, shelf fungi, conks, puffballs, etc. Some of these sporophores open at maturity to expose the basidia, so that the basidiospores may be forcibly released, and others remain closed and are ruptured by natural forces. The presence of these structures on trees, logs, or lumber is of definite diagnostic significance in identifying many wood-rot fungi. These fungi, according to their species, may attack the roots of plants and cause root rots, the heartwood of trees and cause heart rots, or the sapwood of trees and cause sap rots.

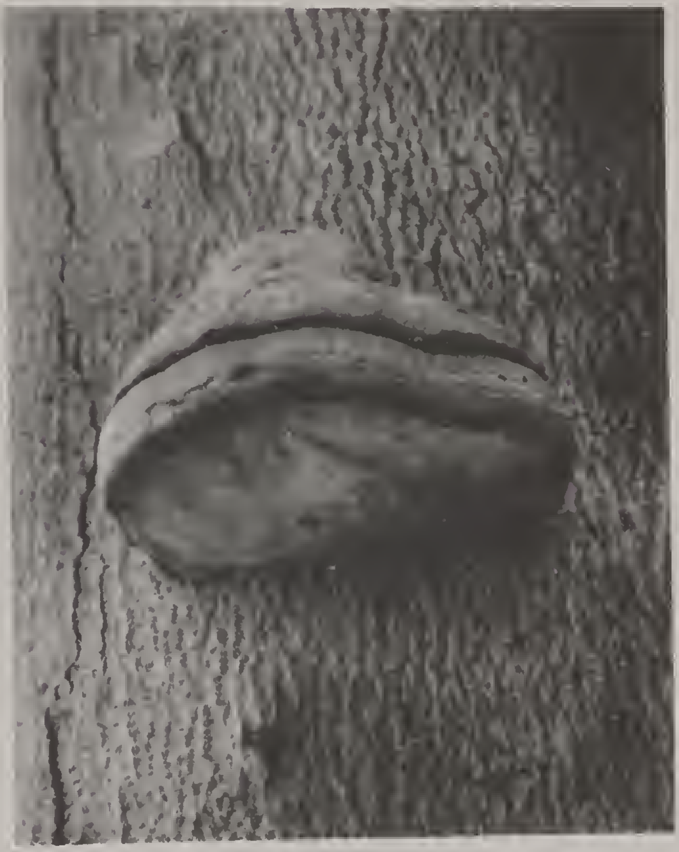


FIG. 141. Shelf fungi (*Fomes igniarius*) on a beech.

TABLE 29

SOME IMPORTANT DISEASES CAUSED BY PALISADE FUNGI

Disease	Causal Organism	Host
Rhizoctonia	*Corticium vagum*	Potato, etc.
Canker	*Septobasidium pedicellatum*	Apple, pear, and some forest trees
Seedling blight	*Typhula* spp.	Cereals, beets, cabbage, etc.
Heartwood or sapwood roots	*Hydnum* spp.	Maple, beech, oak, fir

Table 29 (Continued)

Disease	Causal Organism	Host
Texas root rot	*Hydnum omnivorum*	Cotton, etc.
Timber rot	*Poria incrassata*	Coniferous trees and lumber
White wood rots	*Fomes* spp.	Various deciduous trees
Red heart rot	*Fomes laricis*	Conifers
White rot	*Polyporus squamosus*	Fruit, nut, and shade trees
Dry rot	*Lenzites sepiaria*	Coniferous timber
Schizophyllum rot	*Schizophyllum alneum*	Shade, nut, and fruit trees
White-streaked sapwood rot	*Pleurotus ostreatus*	Maple and deciduous trees
Mushroom root rot	*Armillaria mellea*	Numerous trees
Brown-mottled rot	*Pholiota adiposa*	Deciduous trees and conifers
Sap rot	*Polystictus pergamenus*	Deciduous trees

Fungi Imperfecti

Some 15,000 to 20,000 species are placed in this class, which is made up of the unplaced forms of the fungous world. It is purely an arbitrary and an unnatural classification in which only the conidial or imperfect stage is known. Generally, as soon as the perfect or sexual stage is found, a fungus belonging to this group is transferred to the correct class. Most of the Fungi Imperfecti probably will be found to belong to the Ascomycetes, but some may belong to the Phycomycetes or Basidiomycetes. Fungi Imperfecti include both parasites and saprophytes, some of which are very destructive to plants. The imperfect stages are represented by conidiophores, pycnidia, acervuli, or sporodochia. Some have no spores at all and are grouped in the subclass Mycelia-sterilia. Many Mycelia-sterilia form sclerotia as the resting or overwintering structures. Most of the pathogenic Fungi Imperfecti produce symptoms such as fruit and vegetable rots, leaf spots, wilts, and cankers.

TABLE 30

SOME IMPORTANT DISEASES CAUSED BY FUNGI IMPERFECTI

Disease	Causal Organism	Host
Gray mold or botrytis blight	*Botrytis cinerea*	Buds, fruits, roots, and stems of numerous hosts
Wilt	*Verticillium* spp.	Potato, maple, tomato, etc.
Wilt	*Fusarium* spp.	Cabbage, flax, tomato, potato, cotton, etc.
Leaf spot	*Cercospora beticola*	Beets, etc.
	Cylindrosporium spp.	Cherry and plum
Wilt	*Cephalosporium* spp.	Elm, persimmon, etc.
Anthracnose	*Colletotrichum* spp.	Cucurbits, bean, etc.
Blight	*Coryneum beijerinckii*	Stone fruits
Black leg	*Phoma lingam*	Crucifers
Early blight	*Alternaria solani*	Potato, tomato
Late blight	*Septoria* spp.	Celery
Diplodia disease	*Diplodia* spp.	Corn, citrus
Strumella disease	*Strumella coryneoidea*	Chestnut, oak
Blue mold	*Penicillium* spp.	Apple, pear, citrus

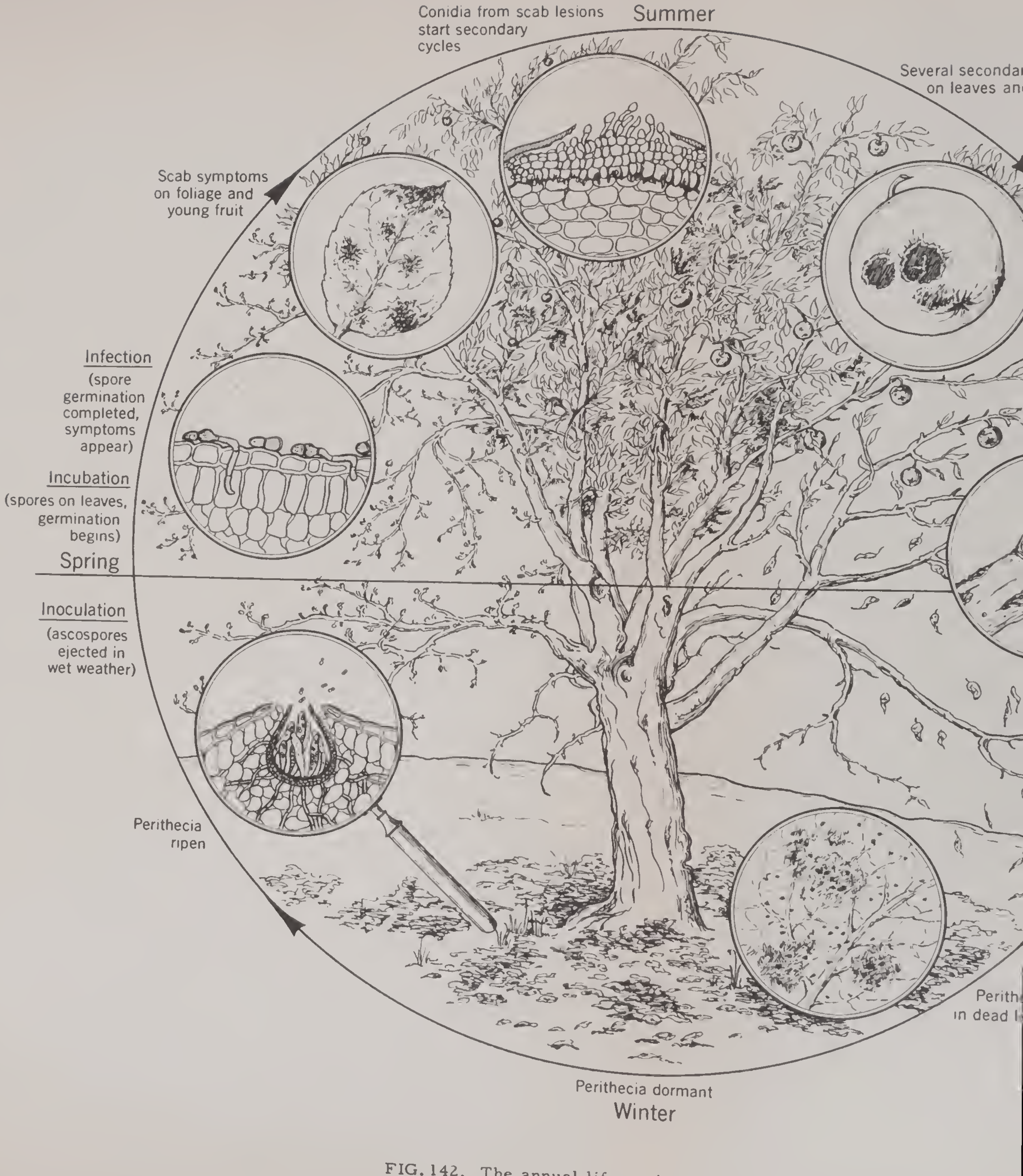

Conidia from scab lesions start secondary cycles
Summer
Several secondar
on leaves an
Scab symptoms on foliage and young fruit
Infection
(spore germination completed, symptoms appear)
Incubation
(spores on leaves, germination begins)
Spring
Inoculation
(ascospores ejected in wet weather)
Perithecia ripen
Perith
in dead l
Perithecia dormant
Winter

FIG. 142. The annual life cycle of the apple scab fungus.

QUESTIONS FOR DISCUSSION

1. How should one proceed to determine the cause of a plant trouble?
2. Which is easier to control, a bacterial disease or a fungous disease?
3. Since plant-attacking bacteria do not form spores, how do the bacteria survive and disseminate themselves?
4. Why must fungi by nature be disease-producing when they live on higher plants?
5. Explain why diseased lesions on foliage are usually round? Why are some angular?
6. In what ways are fungous spores very like the seeds of higher plants?
7. If a sterile nutrient culture medium is exposed to the open air for a short time, it will become contaminated with fungi. What does that show?
8. How are fungous spores disseminated?
9. What does the presence of shelf fungi on a living tree indicate?
10. Why are shelf fungi nearly always present on dead tree trunks or on stumps?
11. Of what importance is it to recognize the reproductive structures of fungi?
12. What are swarm spores and how do they function?
13. What are some of the ways in which fungi overwinter?

Chapter 15

THE ANNUAL LIFE HISTORY OF PATHOGENES

The annual life history of a disease-causing organism consists of all that the organism habitually does, all the stages and cycles that it goes through, and the time spent in each stage from the beginning of its existence (usually in the spring) until 1 year later. The life history is usually made up of one or more life cycles—initiated by the transfer of some reproductive portion of the organism (the inoculum) to a new growing place (the infection court) and completed with the cessation of activity therein.

TYPES OF LIFE CYCLES

There may be two kinds of life cycles: primary ones first initiated by the disease-causing organism after a period of seasonal inactivity (usually after the winter rest); and one or more secondary ones initiated by the inoculum from the primary life cycle or other secondary ones. This applies generally to regions where winter and summer or a dry and a wet season occur. For example, in apple scab the ascospores produced in perithecia in the overwintering leaves on the ground are the source of the primary cycles on the new leaves in the spring. Conidia produced in these primary lesions fall on leaves and fruit and produce secondary cycles and conidia; these in turn produce other cycles, and so on during the summer and fall as long as the weather is favorable (Fig. 142).

Some disease-causing organisms under certain environmental conditions may show only secondary cycles. This usually occurs where climatic conditions are favorable for continuous activity of the organism, for example, in greenhouses and in tropical climates. Carnation rust on carnations perpetuates itself only by a succession of secondary cycles, by means of its urediniospores alone.

THE TWO PHASES IN THE LIFE CYCLE OF PATHOGENES

The annual life history of a disease-causing organism may be represented by a circle, segments of which represent the 4 seasons of the year. A line drawn through the circle separates the two phases usually exhibited during the life history of a disease-causing organism. The disease-producing phase (pathogenesis) occurs during the growing season, whereas the development in dead material or dormant phase (saprogenesis) usually occurs during the cold or (in the tropics) dry season. During pathogenesis the pathogene is usually actively attacking the tissues of its host and producing characteristic symptoms of disease; during its inactive stage the disease-causing organism may be dormant or developing in the dead tissues of its host as a saprophyte.

THE THREE STAGES OF DISEASE ATTACK

During pathogenesis, a pathogene may pass through one or more life cycles each of which exhibits three rather distinct successive stages: the inoculation stage, the incubation stage, and the infection stage. This closely parallels the life cycle of human and animal diseases, which also show these three stages. The length of each of these varies with the nature of the disease-causing organism and that of the host plant, as well as with the environmental conditions involved. Secondary life cycles are represented in the figures by a small circle in which the tree stages are repeated as often as a new cycle occurs.

The Inoculation Stage

This stage begins at the moment that the inoculum leaves its source and ends when it lands on or in the infection court (Fig. 142). Inoculation is the act of transfer of the inoculum from its source to the infection court. The source of the inoculum is generally an infected organ or a lesion on or from some part of a suscept, such as a canker or a diseased leaf or fruit. The soil is also very often a source of the inoculum. An infection court may be a wound or break in the bark or epidermis, water pore, stoma, leaf surface, stigma, flower nectaries, lenticels, etc. on a susceptible plant.

Generally the inoculum is transferred from its source by some agency other than itself and referred to as the inoculating agent or vector (in the case of insects transmitting viruses). The usual inoculating or disseminating agents are air currents, wind, rain, splashing or running water, insects, and many other animal organisms including man. Each disease-producing organism may make use of one or more of these agents for its dissemination.

One of the common methods for inoculum to be introduced into plants is through wounds made by insects in feeding. Many virus and some bacterial and fungous diseases are known to be transmitted by insects, and in some cases insects are the only known inoculating agents.

The Incubation Stage

The incubation stage starts from the moment that the inoculum lands on the infection court and ends with the beginning of the reaction of the plant to the irritation of the disease-producing organism (Fig. 142). The incubation period includes an inactive period or periods, development and germination of the spores, and the entrance (in some cases also the multiplication and spread) of the disease-causing organisms. During this stage the pathogene prepares to attack the living cells or tissues of its host.

The duration of the incubation stage is generally measured from the time when conditions were favorable for the inoculation to take place until the first evidences of disease in the host plant can be detected. This is not an accurate measure: it is not possible to know exactly when the inoculum leaves its source; and the first noticeable reactions of the plant to the invasion of the pathogene occur some time later than actual irritation began. However, this measure is the only practical one to date.

SURVIVAL OF INOCULUM. When the proper environmental conditions are not present for the inoculum to begin activity, it either dies or is able to survive in a quiescent condition for a variable period until favorable conditions arise. Spores vary greatly in their ability to survive conditions unfavorable for incubation. Conidia are able to survive for a few days to several weeks; other spores, such as chlamydospores of smuts, may survive for a year or many years and then germinate under the right conditions. When conditions become unfavorable for further development during the incubation stage, the inoculum may perish, or its activity is temporarily halted, to resume again later when conditions become favorable.

ACTIVITY OF THE INOCULUM. In most cases the inoculum begins activity as soon as it lands on the infection court, since the damp or wet conditions necessary for inoculation usually carry over into the incubation period. During the incubation period spores germinate by sending out an infection thread, in contrast to the inoculum of bacteria and viruses that must gain entrance into the plant tissues to start incubation, multiplication, and spread. The conidia of some powdery mildews germinate best in fairly dry conditions. Some fungous spores will germinate regardless of where they land, provided they have the right temperature and moisture conditions; but others require in addition a chemical stimulus from the tissues of their host before germination will occur.

Most disease-causing organisms must enter the tissues of the host to produce disease. Some are capable of penetrating directly through the uninjured cuticle and epidermis; others enter only through natural openings; and still others can enter only through wounds or lesions. Ingress of fungous pathogenes into host tissues is the final act of incubation. It is this final act that most protective fungicides tend to prevent.

The Infection Stage

This stage includes that portion of disease activity during which the disease-causing organism is irritating the plant and producing symptoms characteristic of this irritation (Fig. 142). This stage begins with the first reaction of the plant to the presence of the organism (latent infection) and ends with the final reaction (usually death) of the plant or plant part to the activities of the pathogene. The infection stage may be short or long, often extending for years before the plant succumbs from the effects. Plant recovery from a disease is usually rare unless infection is confined to the leaves or fruit of trees or shrubs. The period of infection may last from a few days to several years, depending on the nature of the pathogene, age and type of host tissues, temperature, moisture, and possibly other factors. Brown rot on stone fruits destroys all living cells within a few days; but certain heart rots of trees continue their infection for years without destroying the trees. Potato mosaic infection may extend endlessly through the medium of the tubers.

During the active period of infection the pathogene is growing, spreading, and multiplying; and the suscept shows primary and secondary symptoms. Then activity may gradually cease, and secondary decay or healing may set in. In many cases secondary decay or healing goes on during active infection.

PROGRESS OF INFECTION. Infection may be continuous or discontinuous. Infection in some diseases may be stopped permanently or temporarily by unfavorable temperature, water supply, host activity, etc., and may continue again when conditions become favorable. Many canker diseases such as fire blight and black rot of apple and some leaf diseases such as alternaria blight of potatoes and frog-eye (black rot) on apple leaves show zonations due to alternate halting and renewing of infection activities. Often infection is continuous and ends only with the death of the plant or plant organ invaded.

INFECTION AREAS. Many organisms causing plant diseases show a definite preference for or restriction to certain plant tissues or organs. A number of bacterial and fungous pathogenes invade the xylem vessels and cause wilts of various plants; some are limited to sapwood or heartwood, causing wood rots; but the majority confine themselves to the phloem and to parenchymous tissues such as the cortex, and to leaf and fruit parenchyma, causing cankers, leaf spots, rots, galls, etc.

NATURE OF THE ATTACK. Disease-producing organisms may injure plants in a number of ways:

1. They may affect cells or tissues by means of toxins that they produce, as in the case of certain plant wilts and the Dutch elm disease. These toxins may produce overstimulation, inhibition of growth, or death of cells.

2. They may rob cells or tissues of food through their haustoria or by enzymic action within the plant.

3. They may penetrate into cells and destroy their cytoplasmic membranes. The earliest symptom of many diseases is a water-soaked appearance of the tissues, indicating a breakdown of the cell membranes.

4. They may make it easy for secondary pathogenes to gain entrance and break down tissues further, as in the case of numerous rots.

ENVIRONMENTAL CONDITIONS IN RELATION TO INFECTIOUS DISEASE OUTBREAKS

CONDITIONS NECESSARY FOR AN ENPHYTOTIC. When a destructive plant disease sweeps over an area it is referred to as an epiphytotic disease. Epiphytotic diseases may be local, involving only small areas, or they may be widespread, involving large areas, states, and even continents. Three conditions are necessary for a disease to become ephipytotic: (1) an abundance of inoculum; (2) concentrations of host plants in a susceptible stage of growth; and (3) favorable environmental conditions for the initiation and completion of the inoculation, incubation, and infection stages of the pathogene's primary and secondary life cycles. Inoculum for an enphytotic may originate from a few infected plants, from infected seed and lack of crop rotation, from overwintering spore stages, or from secondary life cycles. The amount of injury to any crop is governed by the degree of variation of the three conditions above from the optimum for each particular disease.

Many diseases appear nearly every year with little damage to crops. These are termed sporadic diseases, but occasionally they may become epiphytotic under favorable conditions.

ENVIRONMENTAL FACTORS AND ENPHYTOTICS. Environment, by its effects on the disease-producing organism, on the inoculating agents or vectors, and on the host plants, either favors or does not favor the development of a disease. The environmental factors involved are (1) soil conditions: physical, chemical, and biological composition; water content; availability of nutrients; and chemical reaction (pH); (2) and atmospheric conditions: temperature; moisture; sunlight; and wind. All these factors interact with one another to affect both the disease-producing organism and the suscept at the same time. However, factors favorable for the development of the disease-producing organism are not always optimum for host susceptibility, and vice versa. Each disease and each stage of a disease has an ideal range for each environmental factor, and any departure from this range tends to reduce the prevalence of the disease.

Environment not only influences the growth of plants but also causes them to vary in their susceptibility to disease invasion. A plant may be very susceptible under one set of environmental conditions and highly resistant under another. Enphytotics occur locally in many areas every year, and generally control or preventive practices are designed to alter one or more of the three predisposing factors mentioned previously. Some of the most destructive enphytotics have been caused by disease-producing organisms new to a particular area and to a highly susceptible host. The chestnut blight and the Dutch elm disease are examples of such enphytotics.

Temperature and Moisture. These are two of the most important interacting factors regulating disease outbreaks. The majority of bacterial and fungous disease-producing organisms require moisture or damp conditions for definite periods within a definite temperature range for the liberation of the inoculum and the completion of the incubation stage on the infection court (Fig. 143). Some of the powdery mildews, however, can complete incubation under dry conditions.

Optimum air or soil temperatures vary greatly with different disease-producing organisms (Table 31) and even with the different stages that make up the life cycle. For example, the organism causing late blight of potatoes requires wet foliage and cool air temperatures for optimum inoculation and incubation (Fig. 144) but humid, warm temperatures for optimum infection progress.

In general, it may be stated that diseases tend to become ephiphytotic in seasons of the year marked by abundant rainfall, long wet periods, or fogs, as long as temperatures remain within the effective range of development of the disease-producing organisms. In wet, rainy springs and summers numerous diseases may be expected to show up on plants, whereas in dry springs and summers most diseases are scarce or practically nonexistent. Many of our destructive plant disease-producing organisms, such as those that cause fusarium wilts, onion smut, rhizoctonia of potatoes, potato scab, and carotovorus soft rot may survive several years in the soil under the proper temperature and moisture conditions.

Soil Reaction and Infectious Diseases. Disease-producing organisms vary greatly in their requirements of the pH of soil or plant juices. Diseases such as cotton wilt, tomato wilt, rhizoctonia root rot, and the club root of crucifers are

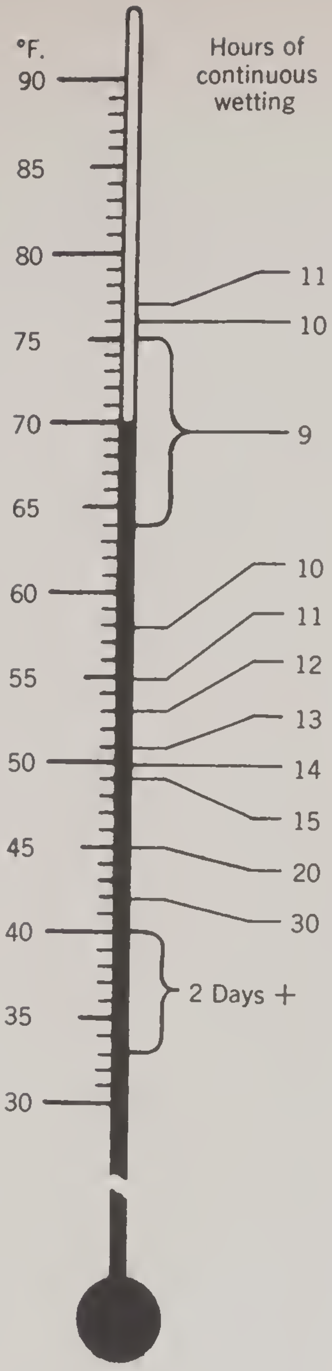


FIG. 143. Hours of continuous wetness necessary at various temperatures to complete the inoculation and incubation stage of the apple scab fungus in the spring (redrawn from Mills and Dewey, (Cornell Ext. Bull. 711).

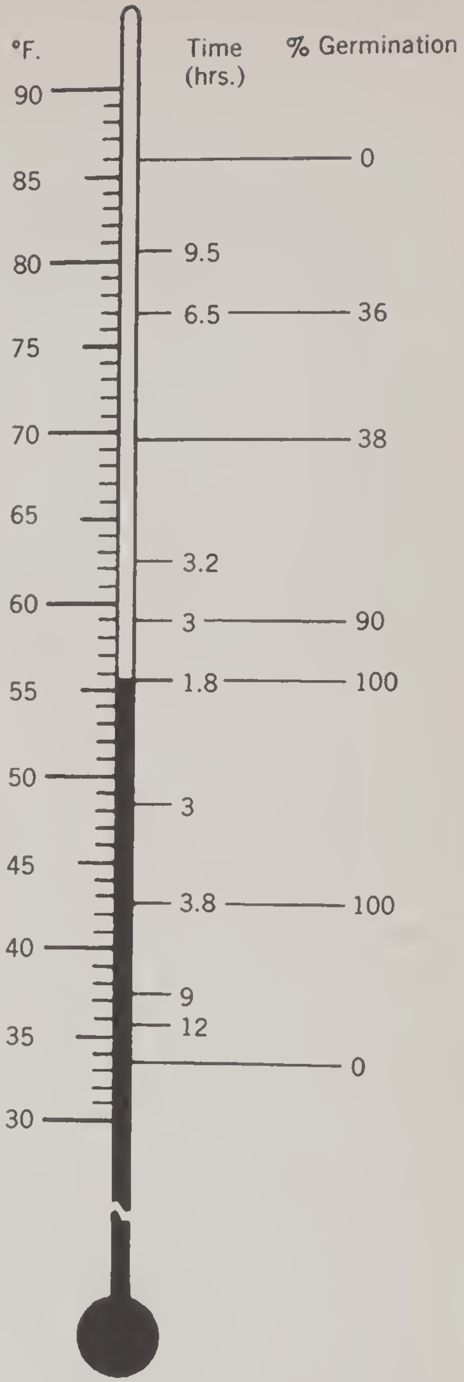


FIG. 144. Relation between time, temperature, and per cent germination of potato late blight conidia under optimum moisture conditions (based on data from Melhus and Kent, Elements of Plant Pathology.

TABLE 31

OPTIMUM INCUBATION TEMPERATURES OF SOME DISEASES UNDER THE PROPER MOISTURE CONDITIONS (Data from various sources)

Disease	Air Temperatures
Apple scab	65-75° F.
Brown rot	high
Cedar-apple rust	65° F
Late blight of potato	52.6° F.
Peach leaf curl	low
Pysoderma disease of corn	82-84° F.
	Soil Temperatures
Fusarium wilt of tomato	80.6° F.
Bunt of wheat	60-64° F.
Onion smut	50-54° F.
Cabbage yellows	79-84° F.
Watermelon wilt	78-82° F.
Potato rhizoctonia	59-70° F.

favored by a low pH or acid soil reaction; whereas Texas root rot, potato scab, black root rot of tobacco, and soil rot of sweet potatoes are favored by a high pH or alkaline soil reaction. These diseases are often controlled by altering the soil reaction, but what actually takes place in the plant or soil to make conditions unfavorable for the disease is often not clearly understood. Varietal resistance to disease may in many cases be due to unfavorable chemical reaction for the disease-producing organism within the plant tissues.

THE LIFE HISTORIES OF SOME DISEASE ORGANISMS

Late Blight of Potatoes (caused by *Phytophthora infestans*)

Host Plants. Potatoes, tomatoes.

Symptoms. Waterlogged dark spots that spread rapidly, killing the leaves. In dry weather the leaves turn dark brown, but in damp weather the leaves remain dark with white groups

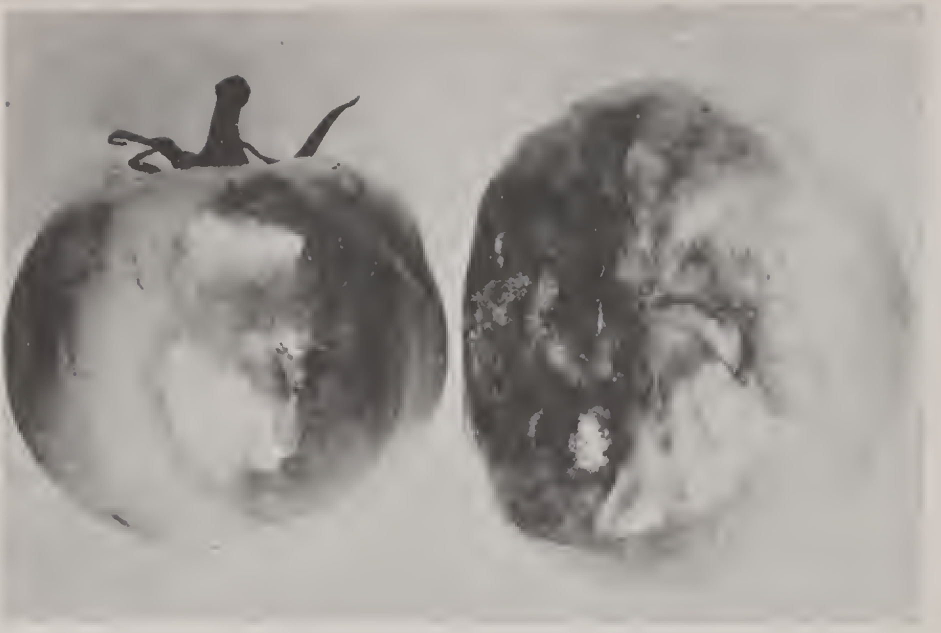


FIG. 145. Late blight produces a rot in tomatoes.

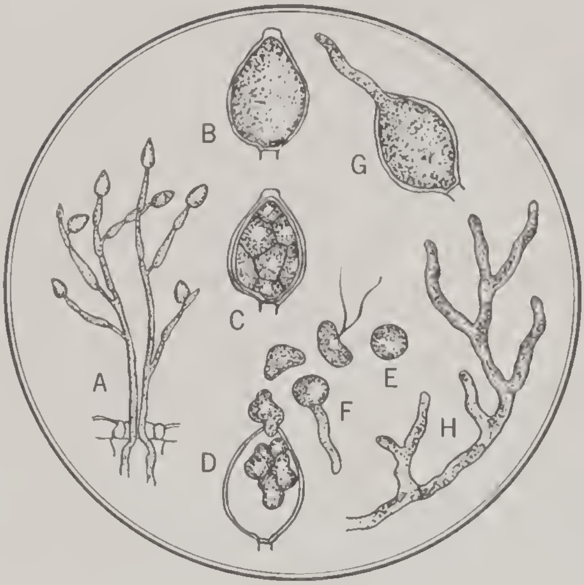


FIG. 146. The late blight fungus of potatoes. A, conidiophores bearing conidia; B, C, D, zoöspore formation from a conidium; E, F, resting and germinating zoöspore; G, direct germination of a conidium; H, mycelium of fungus (redrawn from Melhus and Kent, Elements of Plant Pathology).

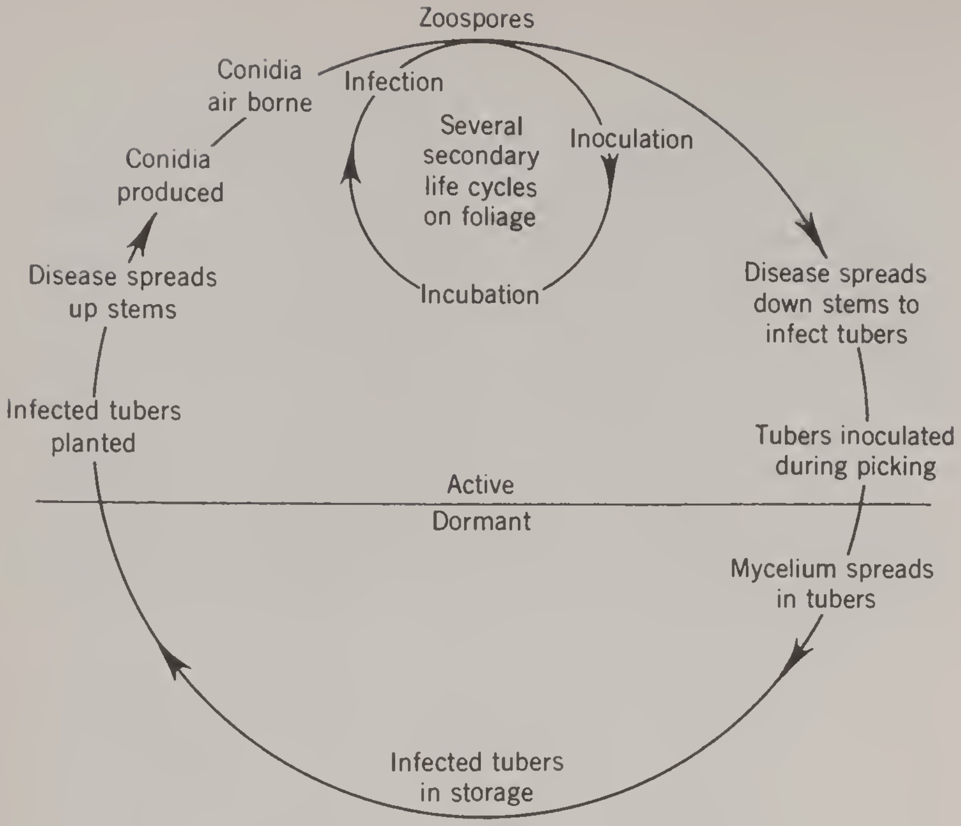

Zoospores
Conidia air borne
Infection
Several secondary life cycles on foliage
Inoculation
Conidia produced
Disease spreads up stems
Incubation
Disease spreads down stems to infect tubers
Infected tubers planted
Tubers inoculated during picking
Active
Dormant
Mycelium spreads in tubers
Infected tubers in storage

FIG. 147. The annual life history of the late blight fungus of potatoes.

of conidiophores and conidia covering the affected areas (Fig. 105). Stems, tubers, and fruits may also be attacked, resulting in dry or wet rots depending on the humidity (Fig. 145).

Life History. See Figs. 146 and 147. Two races are present in the United States; only one is virulent enough to attack tomatoes. Repeatedly growing the pathogene on highly resistant varieties has been shown to increase its virulence so that resistant varieties may be attacked severely. The disease is usually brought to a field in infected seed pieces, but airborne spores are responsible for enphytotics.

Fire Blight (caused by Erwinia amylovorus)

Host Plants. Pear, apple, quince, and many other plants of the family Rosaceae.

Symptoms. The organism thrives in succulent, vigorous-growing tissues. During its development it may cause such

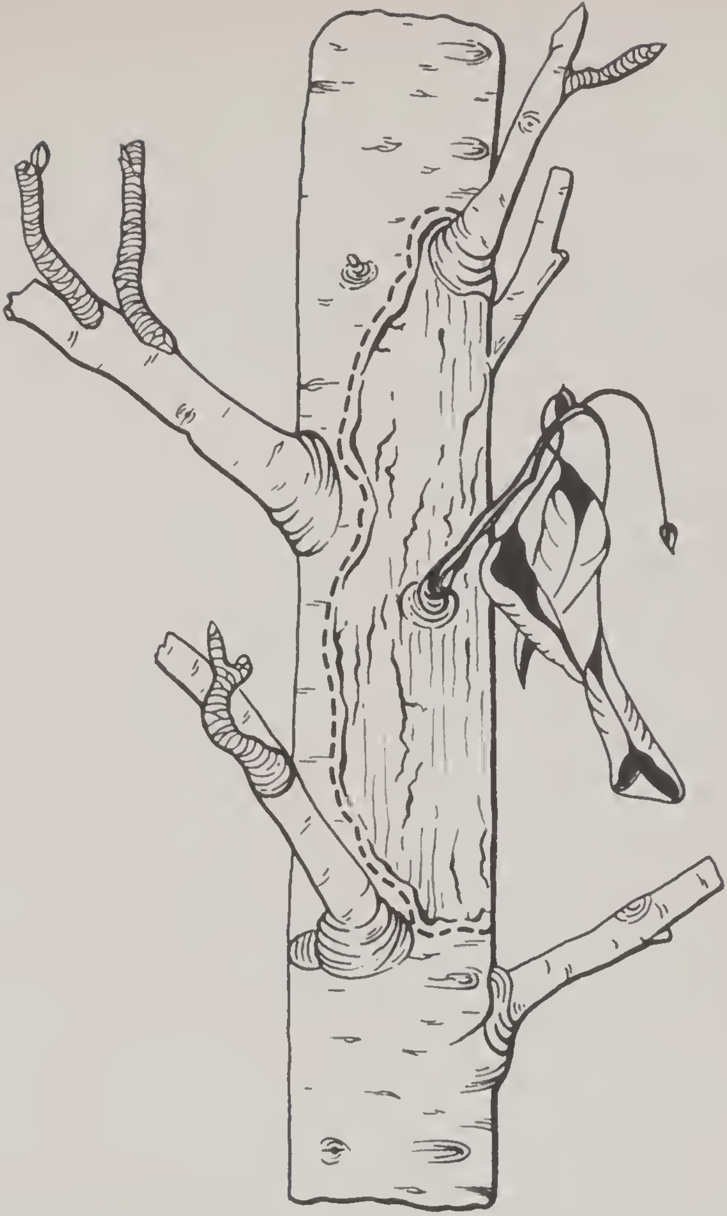


FIG. 148. A fire blight canker in the dormant season. Dotted line indicates location of bacteria (after Hildebrand, Cornell Ext. Bull. 405).

symptoms as leaf blight, fruit blight, blossom blight, twig blight, and branch and trunk cankers. The dead leaves and fruit cling to the branches and do not fall off readily (Fig. 148).

Life History. See Fig. 149. Inoculation takes place mainly through nectaries, stomata, lenticels, and wounds. The dissemination of bacterial is mainly by insects and rain.

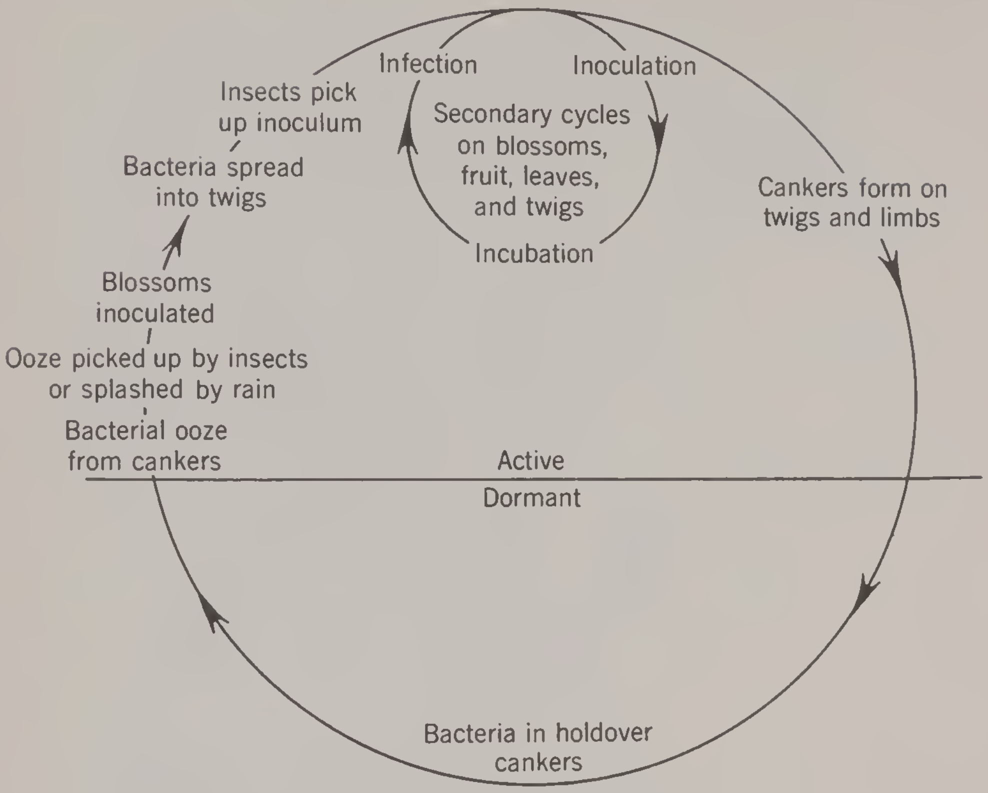

Infection
Inoculation
Secondary cycles on blossoms, fruit, leaves, and twigs
Incubation
Insects pick up inoculum
Bacteria spread into twigs
Blossoms inoculated
Ooze picked up by insects or splashed by rain
Bacterial ooze from cankers
Cankers form on twigs and limbs
Active
Dormant
Bacteria in holdover cankers

FIG. 149. The life history of the fire blight bacterium (Erwinia amylovorus).

Damping-off (caused by Pythium debaryanum)

Host Plants. Seedlings of most plants, especially those grown in greenhouses, coldframes, and hotbeds.

Symptoms. Damping-off may be caused by several other pathogenes, but the one above is the most important. In pre-emergence damping-off the seeds or seedlings rot before emergence takes place. In post-emergence damping-off the seedlings are attacked at the soil line or below; they wilt and then fall over.

Life History. See Figs. 150 and 151.

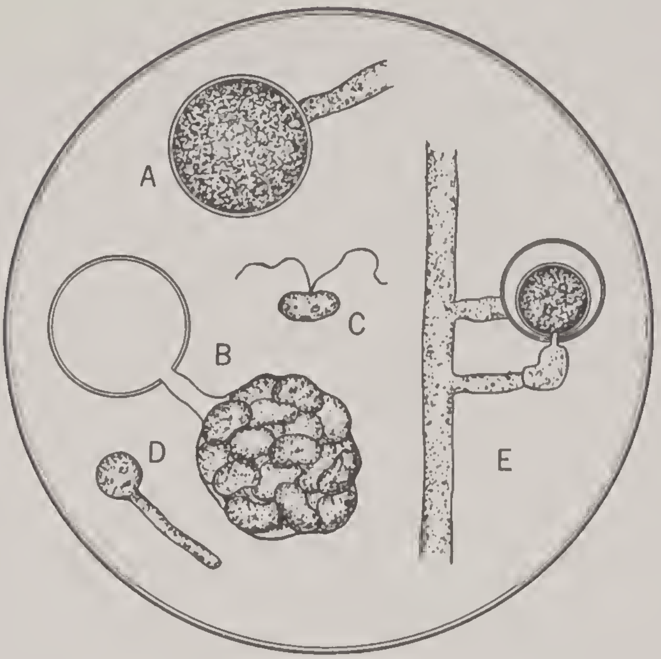


FIG. 150. The reproductive structures of the fungus causing damping-off. A, conidium; B, germinating conidium; C, zoöspore; D, germinating zoöspore; E, the formation of an oöspore (redrawn from Melhus and Kent, Elements of Plant Pathology).

Cotton Wilt (caused by Fusarium vasinfectum)

Host Plant. Cotton.

Symptoms. Premature wilting and death of plants. Brown or black discoloration of the vascular bundles appears in the roots and stem. Symptoms are most evident when plants are 8 to 12 inches high, but the same fungus may also cause a seedling rot and early wilt similar to damping-off. The disease is most prevalent in light, sandy soils.

Life History. See Fig. 152. Disease is disseminated by implements, animals, water, and wind.

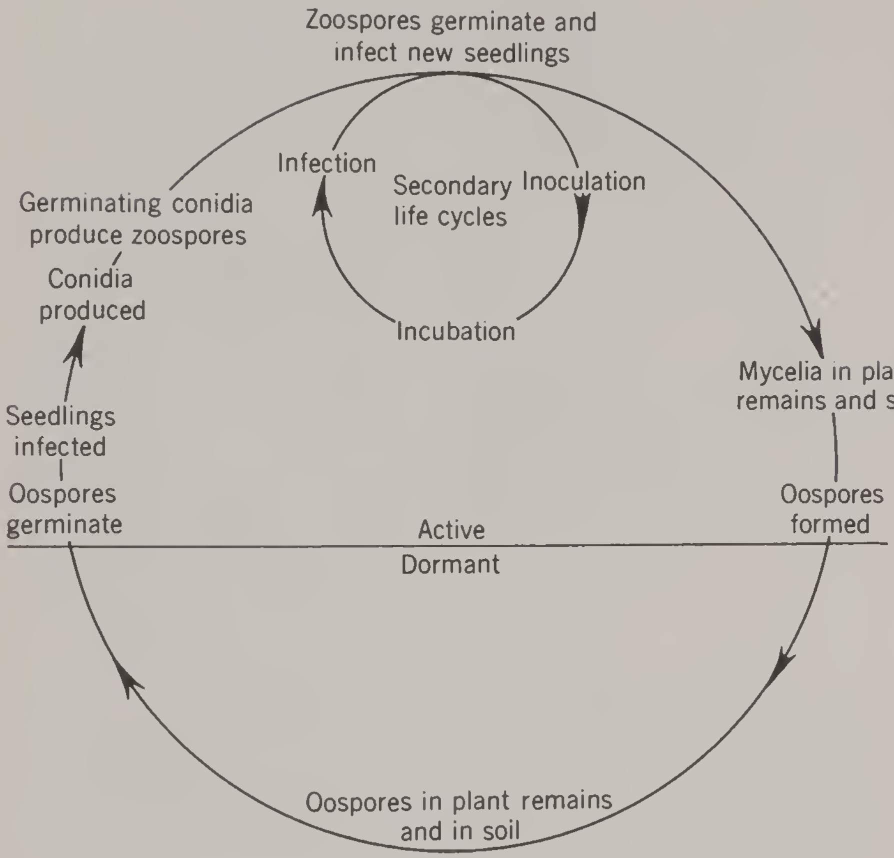

Zoospores germinate and infect new seedlings
Infection
Secondary life cycles
Inoculation
Incubation
Germinating conidia produce zoospores
Conidia produced
Seedlings infected
Oospores germinate
Mycelia in plant remains and soil
Oospores formed
Active
Dormant
Oospores in plant remains and in soil

FIG. 151. The life history of the damping-off fungus (Pythium debaryanum).

Soft Rot of Vegetables (caused by Erwinia carotovorus)

Host. Most root crops and some other vegetables such as lettuce, cabbage, celery, and tomatoes.

Symptoms. Produces a soft, slimy rot of the infected tissues, usually roots. Epidermis may remain intact with the rot internal. Rot produces a very foul odor and may develop in storage as well as in the field, under warm, damp conditions.

Life History. See Fig. 153. The organisms are easily spread by contact, tools, insects, contaminated manure, etc.

Brown Rot of Stone Fruits (caused by Sclerotinia fructicola)

Host Plants. Peach, plum, cherry, apple, and apricot.

Symptoms. The brown rot fungus may attack the flowers and leaves, producing a blight; the twigs, producing cankers; and the fruit, producing a brown rot. Light-brown, tufted conidiophores usually cover the necrotic lesions on flowers and fruits (Fig. 110). Blossom blight occurs under hot, damp conditions. The disease organism usually travels down the flower petiole and enters the stem, producing a girdling canker that wilts and kills the growth above. Fruit is most susceptible when it is ripe and has lesions caused by the plum curculio or scab.

Life History. See Figs. 154 and 155.

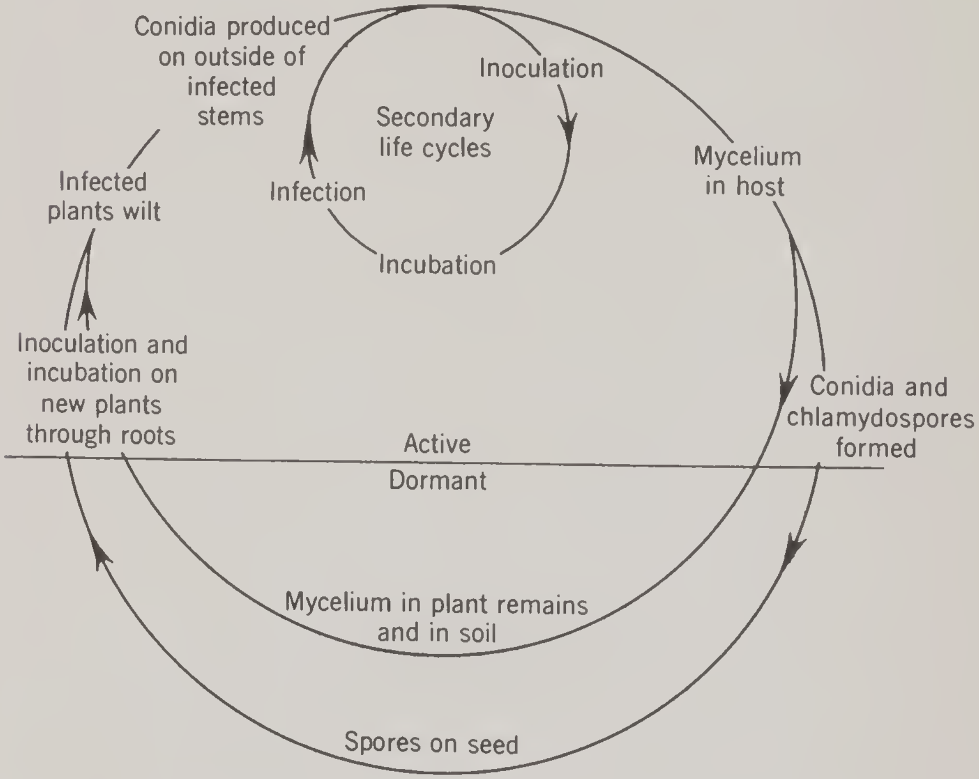

Conidia produced on outside of infected stems
Inoculation
Secondary life cycles
Mycelium in host
Infected plants wilt
Infection
Incubation
Inoculation and incubation on new plants through roots
Conidia and chlamydospores formed
Active
Dormant
Mycelium in plant remains and in soil
Spores on seed

FIG. 152. The life history of the cotton wilt fungus (Fusarium vasinfectum).

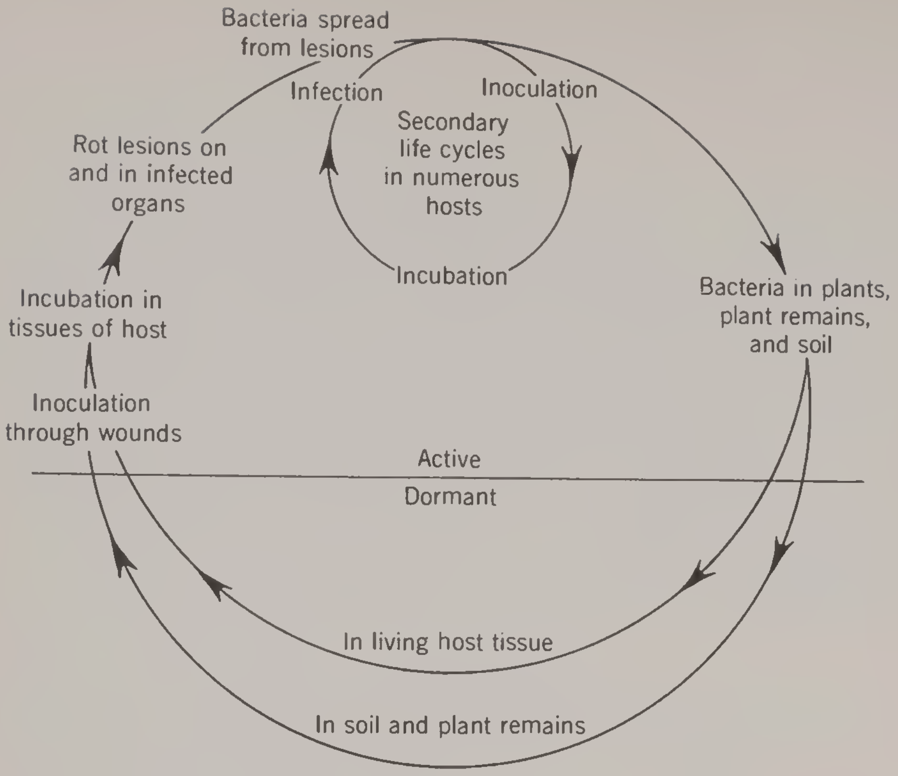

Bacteria spread from lesions
Infection
Inoculation
Secondary life cycles in numerous hosts
Incubation
Rot lesions on and in infected organs
Incubation in tissues of host
Inoculation through wounds
Bacteria in plants, plant remains, and soil
Active
Dormant
In living host tissue
In soil and plant remains

FIG. 153. Life history of the soft rot organism (Erwinia carotovorus).

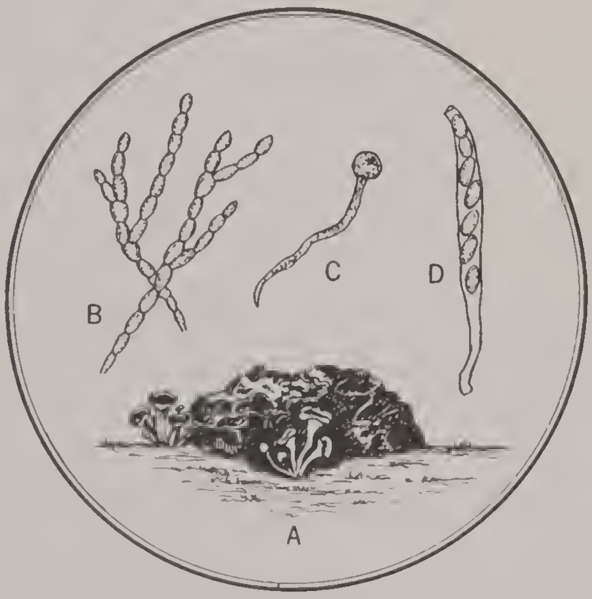


FIG. 154. Brown rot of stone fruits. A, a plum mummy with apothecia; B, conidia; C, conidium germinating; D, an ascus.

White Heart Rot of Hardwoods (caused by Fomes igniarius)

Host Plants. Many deciduous trees, especially hardwoods such as oak, maple, birch, willow, apple, butternut, and aspen.

Symptoms. Fungus attacks mainly the heartwood of the trunks of growing trees as well as of dead trees. Discolored, irregular, yellowish-white areas bounded by dark bands characterize the invaded wood. The fungus sometimes invades and destroys the sapwood and bark of trees.

Life History. See Figs. 141 and 156.

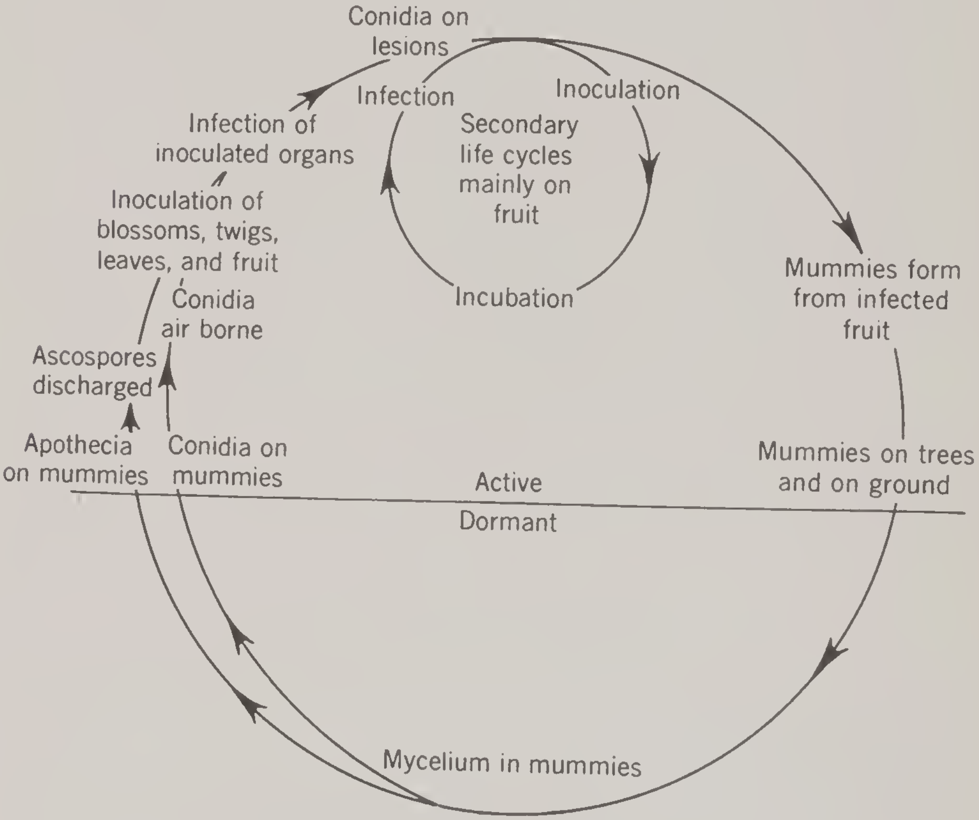

Conidia on lesions
Infection
Inoculation
Secondary life cycles mainly on fruit
Incubation
Infection of inoculated organs
Inoculation of blossoms, twigs, leaves, and fruit
Conidia air borne
Ascospores discharged
Apothecia on mummies
Conidia on mummies
Mummies form from infected fruit
Mummies on trees and on ground
Active
Dormant
Mycelium in mummies

FIG. 155. The life history of the brown rot fungus (Sclerotinia fructicola) on peach.

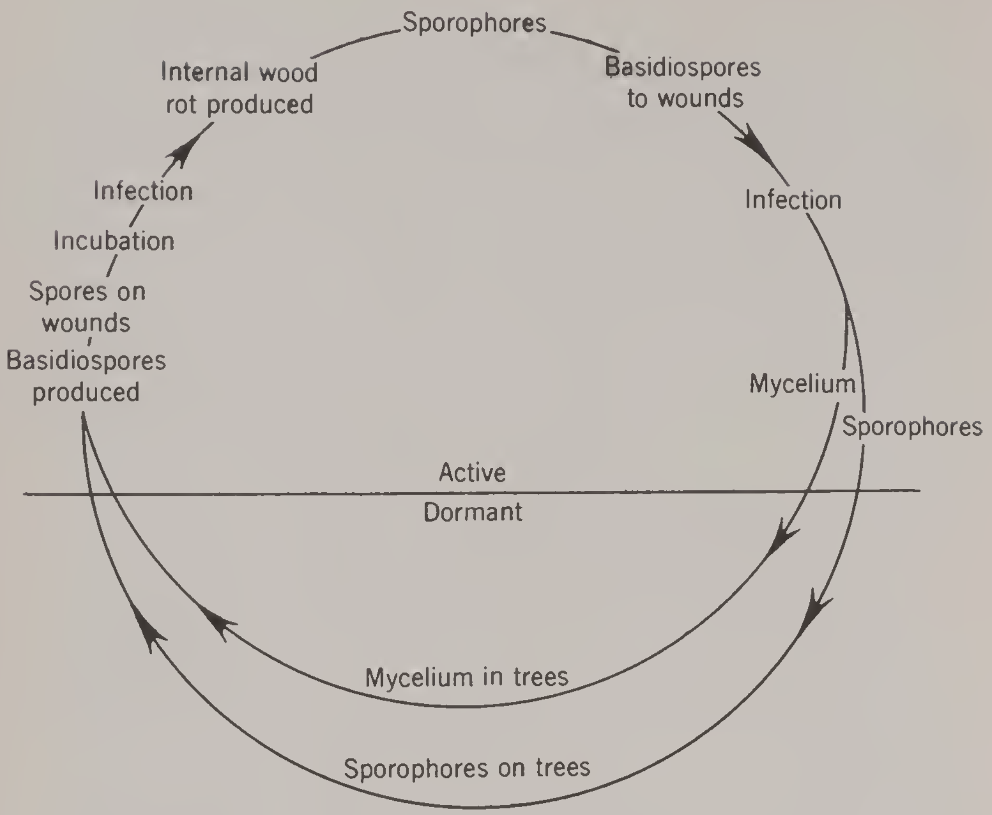


FIG. 156. The life history of the white heart rot fungus, Fomes igniarius.

Black Rot of Apple
(caused by Physalospora obtusa)

Host Plants. Apple, peach, quince, currant, pear, and other woody species.

Symptoms. Fungus may attack leaves, limbs, and fruit. Brown leaf spots usually of a zonate character and referred to as "frog-eye" are produced. The bark of limbs may be roughened or killed and cracked. The limbs are killed when they are girdled by the cankers (Fig. 157). Rot occurs mainly on mature fruit as dark, often zonate, lesions that spread throughout the whole fruit. Fruit turns into a black, shiny mummy with numerous black pycnidia covering it.

Life History. See Fig. 158.

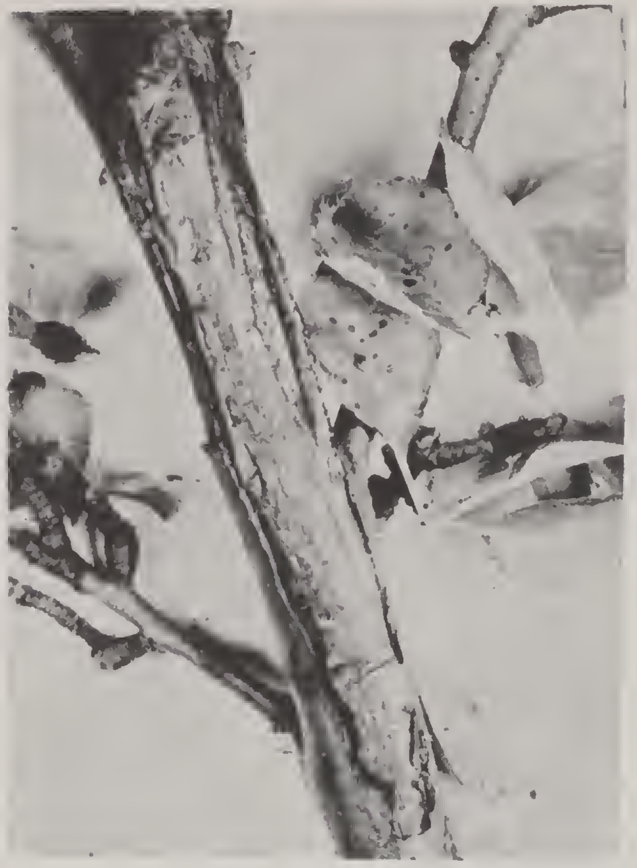


FIG. 157. Black rot canker on apple. Note also the spots caused by the same fungus on the foliage.

Crown Gall
(caused by Pseudomonas tumefaciens)

Host Plants. Most fruits including pome fruits, stone fruits, blackberries, raspberries, loganberries, currants, gooseberries, grapes; also roses, nut trees, numerous woody and herbaceous ornamentals, alfalfa, cotton, beets, turnips, and hops.

Symptoms. This bacterial organism causes tumor-like, rounded, rough enlargements at the crown, roots, trunks, or branches of susceptible plants (Fig. 159). Since the organism can undergo incubation and infection only in wounds it is often found at the point of union of root-grafted stock, but it should not be confused with graft knots, which are overgrowths of excess callus tissue. These galls often interfere with con-

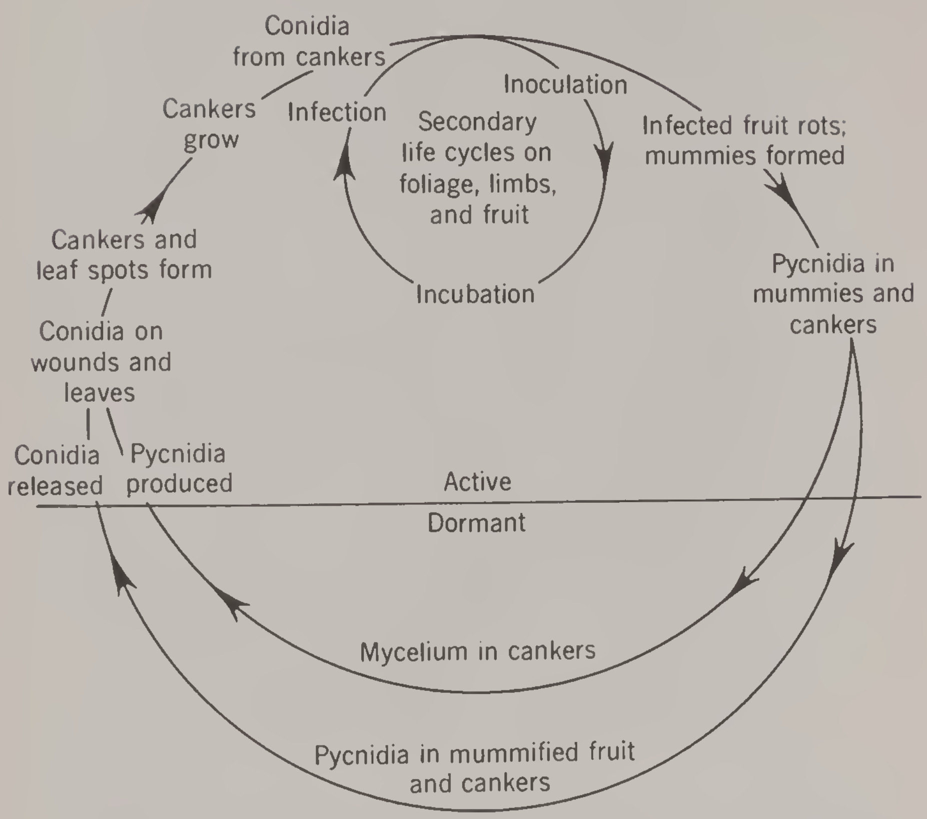

Conidia from cankers
Inoculation
Infection
Cankers grow
Secondary life cycles on foliage, limbs, and fruit
Infected fruit rots; mummies formed
Cankers and leaf spots form
Incubation
Pycnidia in mummies and cankers
Conidia on wounds and leaves
Conidia released
Pycnidia produced
Active
Dormant
Mycelium in cankers
Pycnidia in mummified fruit and cankers

FIG. 158. Life history of the black rot fungus on apple.

duction of water upwards in the plant. Young galls are soft or spongy and creamy white; as they enlarge they become harder and turn dark brown.

Life History. See Fig. 160.

Loose Smut of Wheat (caused by Ustilago tritici)

Host Plants. Wheat, rye, barley.

Symptoms. Black smut masses cover the flower heads of the plants (Fig. 161). These spore masses tend to be broken up, and the spores are distributed by the wind. Smutted heads appear early, just as the normal heads are flowering.

Life History. Smut spores are carried by the wind to flower stigmas where they undergo incubation and infect the ovary. The infection remains dormant in the ovary until the seed that has formed has germinated. Hyphae then travel upward to infect the young spikelets (Fig. 162).

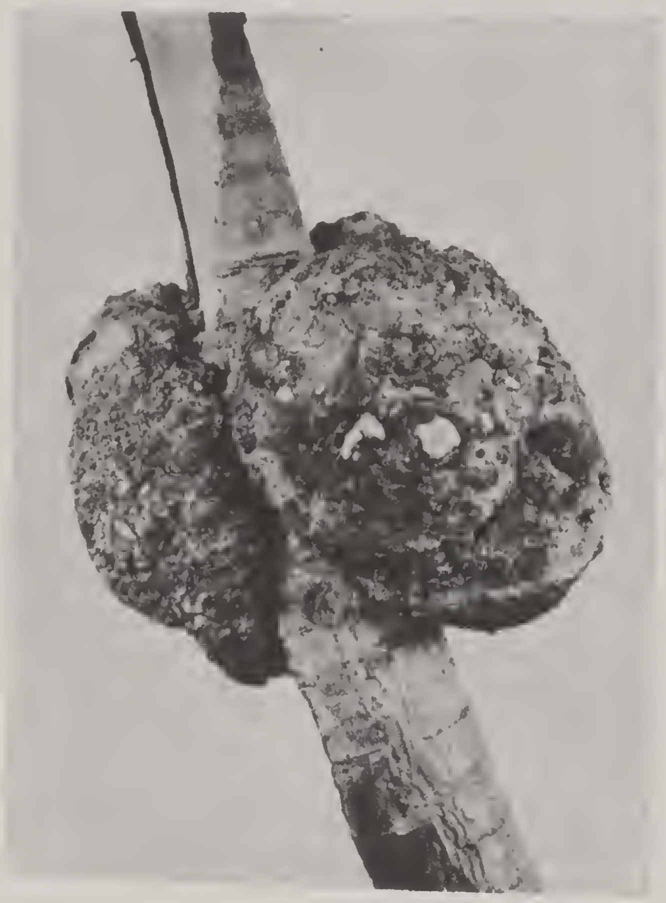


FIG. 159. Crown gall on a peach root.

QUESTIONS FOR DISCUSSION

1. Is a knowledge of the life history of a disease-producing organism necessary for its control?
2. What limits the number of secondary life cycles a disease-causing organism may undergo?
3. Describe the inoculation; incubation, and infection stages of some human diseases.

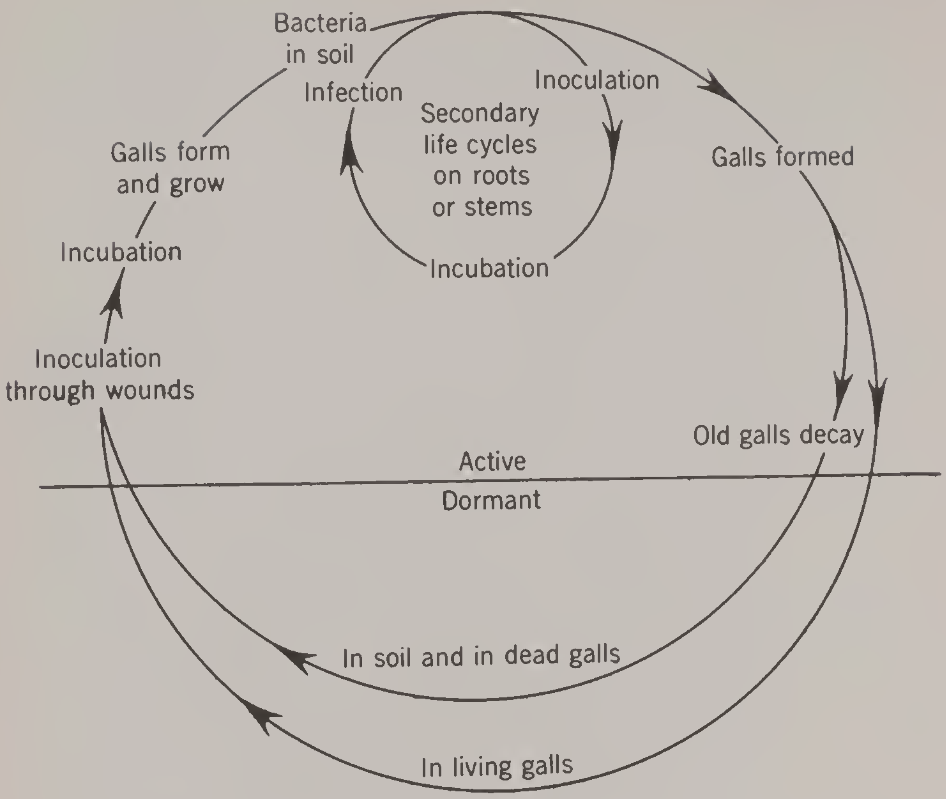


FIG. 160. Life history of the crown gall bacterium (Pseudomonas tumefaciens).

4. Why did people at one time think that diseases arose spontaneously?

5. What conditions favor the inoculation stage of plant diseases?

6. Do these same conditions favor the completion of the incubation stage?

7. What diseases are most likely to become destructive: those in which the inoculum is air-borne, or those in which the inoculum is water- or animal-borne?

8. Why do diseases often seem to appear out of nowhere under favorable conditions?

9. Will disease-causing spores germinate wherever they may be under favorable weather conditions?

10. Why is it too late to apply a protective fungicide after incubation has been completed?

11. What types of diseases may plants recover from?

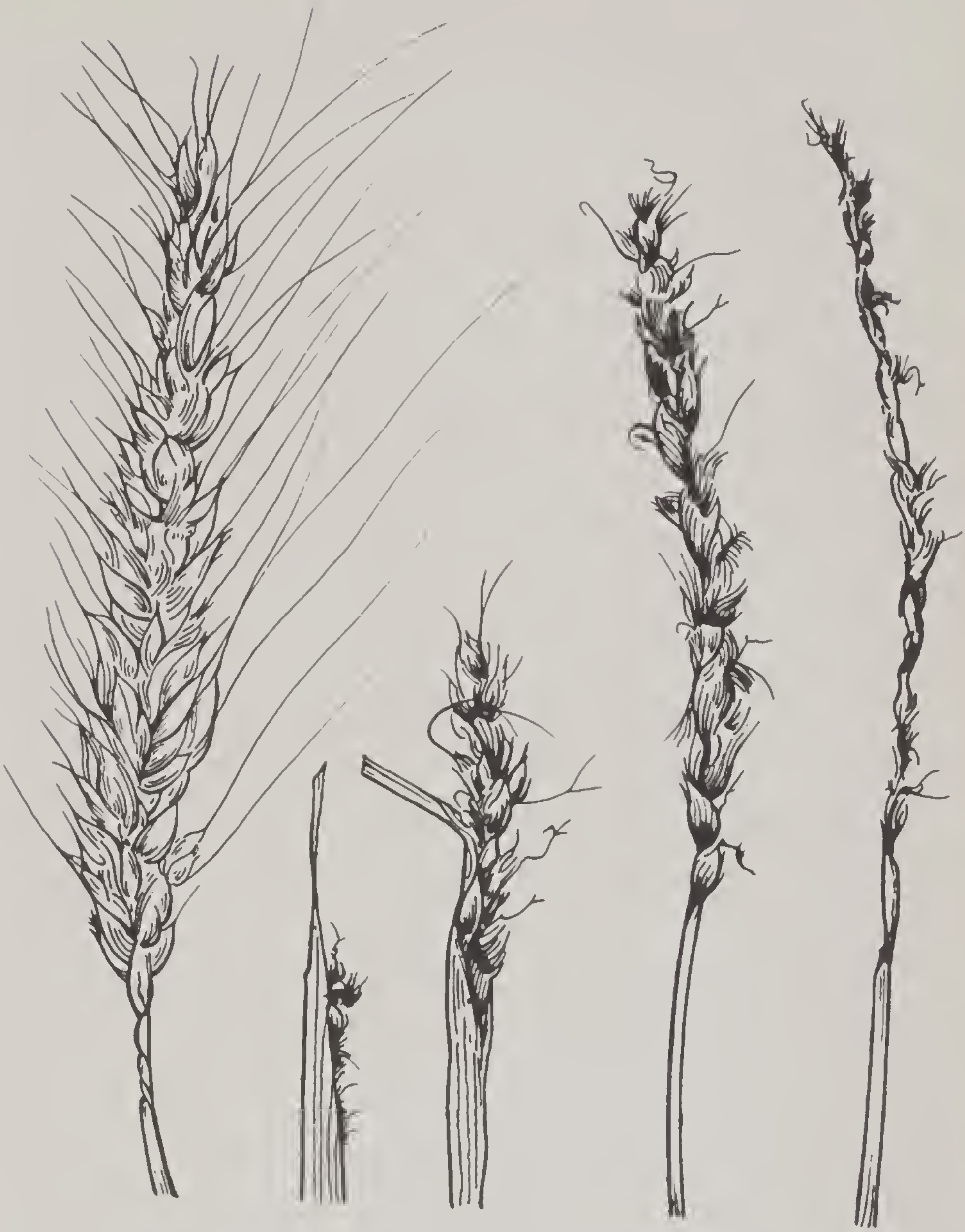


FIG. 161. Loose smut of wheat (redrawn from U.S. Dept. Interior Leaflet 3).

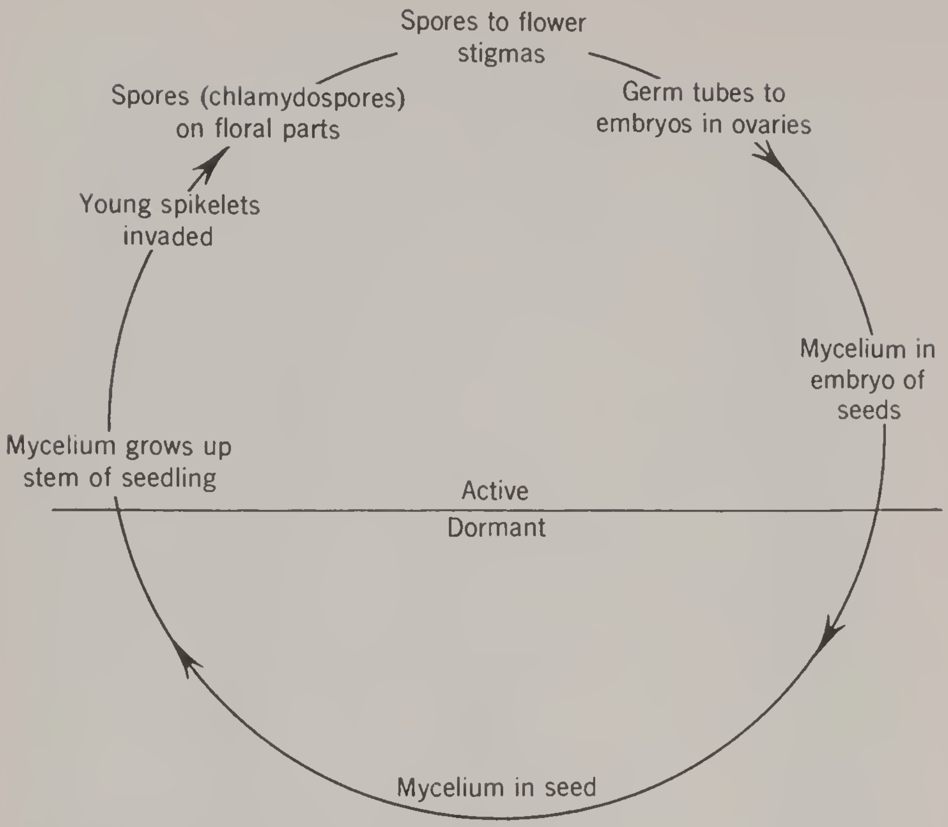

Spores to flower stigmas
Germ tubes to embryos in ovaries
Mycelium in embryo of seeds
Active
Dormant
Mycelium in seed
Mycelium grows up stem of seedling
Young spikelets invaded
Spores (chlamydospores) on floral parts

FIG. 162. Life history of loose smut of wheat (Ustilago tritici).

12. During what stages are plant disease-causing organisms most susceptible to control?
13. What are the conditions that usually lead up to an enphytotic?
14. Do individual plants vary in their susceptibility to disease attack? Varieties of the same species?
15. What effects do growing conditions have on the prevalence of a disease?
16. Do all disease-producing organisms have the same requirements for optimum development?
17. Why do retarded germinating conditions favor poor germination?
18. Why is crop rotation important in the control of fusarium diseases?

19. Which plants are more subject to disease attack: those growing vigorously or those doing poorly?

20. Would it be possible to eradicate a wind-borne pathogene from a given area?

21. Why is good potato land generally quite acid although potatoes do as well or better at a higher pH?

22. Why do potato or tomato late blight enphytotics usually occur late in the growing season?

23. Why isn't the stem rust of wheat wholly eliminated by the destruction of barberry plants in infested areas?

24. Study each of the life histories presented in this chapter and pick out the possible points where each organism may be attacked.

25. Is correct timing of control measures more important in insect or disease control?

26. Why are chemical measures for disease control best made before rainy periods?

27. Why is fire blight difficult to control once it gets started in an orchard?

28. If apple scab overwinters mainly in the dead leaves, why is the destruction of the dead leaves not a standard practice in commercial orchards?

29. Is this statement correct: most organisms causing rot disease can get started only in lesions?

30. Does a tree's condition have any effect on its susceptibility to wood rots? Cankers?

31. What disease-causing organisms may be carried from plant to plant by means of pruning tools?

Chapter 16

VIRUSES AND PHYSIOPATHS AS THE CAUSE OF PLANT DISEASES

VIRUSES AS CAUSES OF PLANT DISEASE

Viruses are the causes of many harmful and often fatal diseases such as smallpox, typhus fever, measles, mumps, and rabies that attack man and animals. Plants also exhibit an imposing and growing number of infectious diseases caused by viruses, but these are not known to be transmissible to animals. The term "degenerative diseases" has often been applied to plant diseases caused by viruses because these diseases tend to produce a gradual but progressive loss of vigor.

THE NATURE OF VIRUSES. The nature of the entities causing virus diseases were long a mystery because they could neither be seen through the most powerful microscope, nor filtered by the finest bacterial filters. The electron microscope has revealed a new world of submicroscopic objects that are considered to be the virus particles or bodies themselves.

The smallest bacteria, which measure about 1x1/2 microns, are ten to one hundred times larger than virus particles. They may be of several forms: long and short rods and separate or clustered spherical bodies. They have characteristics that place them in both the living and in the non-living worlds.

The characteristics that place them in the living world are: (1) their ability to multiply in cells or tissues after inoculation and produce disease symptoms after a more or less constant elapsed time; (2) their dependence on living cells for growth and reproduction; (3) their fixed thermal death point, which varies with the virus; (4) their ability to form many distinct strains; and (5) their selective host ranges. Usually a given virus tends to attack only plants in one family, but some, such as curly top virus of beets, have been found to attack 220 host species in 41 families; and some, such as corn mosaic virus, have been found only in corn and sorghum.

The characteristics that place them in the non-living world are their ability to act like lifeless chemicals in the test tube and to be crystallized out of solution, at least in some cases in the form of a highly infectious crystalline protein. This has led to the theory that viruses are large, high-molecular-weight protein molecules capable of multiplying when they are in living tissues and of acting like living organisms, but acting like lifeless chemicals when they are separated from their living hosts. It is possible that viruses are one of the connecting links between the living and non-living worlds.

Symptoms of Virus Disease

Virus diseases are usually systemic but some may remain localized. They are much more common in herbaceous plants than in woody plants. Viruses usually do not kill plants outright but produce a slow degeneration with stunting and death of tissues as the final symptoms. Some virus diseases are so mild that the plants may bear a crop although it is usually inferior in quality and quantity. In some cases apparent recovery has been noted, but it may be more of a case of resistance or masking of symptoms, as such plants still have the virus in their cells. It has been noted that weather and growth conditions affect the severity of the symptoms. Generally symptoms are most severe in cool weather and under poor growing conditions and are less severe or even masked under warm, vigorous-growing conditions. Symptoms are usually hypoplastic, but many virus diseases also produce hyperplastic or necrotic symptoms.

Viruses may produce one or more of the following disease symptoms in plants:

1. Paling. General paling of leaves and other green parts as exemplified by aster yellows, peach yellows, raspberry yellows, tomato yellows (Fig. 163).

2. Mottling of foliage or fruit caused by irregular, alternate patches or spots of light green or yellow and normal green. Puckering and wrinkling and stunting of growth often accompany this symptom which is characteristic of a number of virus diseases known as mosaics (Fig. 113). Mottling of the petals of sweet peas and petunias is caused by mosaics, whereas breaking of tulips (production of variegated flowers by solid color varieties) is caused by a virus infection that is perpetuated in some commercial varieties.

4. Stunting and shortening of internodes (rosetting). One

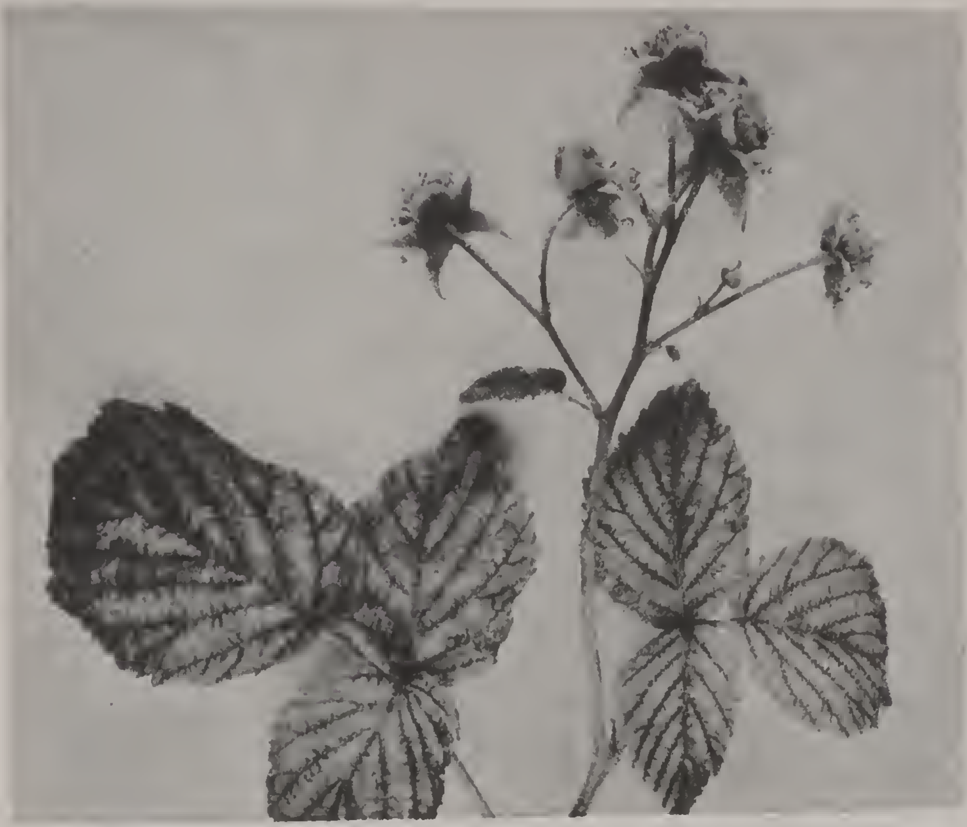


FIG. 163. Raspberry yellows. Note pale, undersized leaves.

or both of these symptoms may commonly accompany the previous symptoms. Examples are rosette of peach, dahlia stunt (Fig. 164), little peach, dwarf of bramble fruits, and witches' broom effect on various plants (Fig. 119).

4. Rolling and curling of leaves as found in leaf roll of grape, curly top of beets, potato leaf roll, and leaf curl of raspberries.

5. Distortion and malformation of leaves as shown by puckered, twisted, or narrowed leaf surfaces. Examples are shoe-string and fern leaf of tomato (Fig. 165), delphinium stunt, and pepper mosaic.

6. Ring spot. Yellowish rings with necrotic or chlorotic centers on the green background of the leaves, as found in ring spot of dahlias, peonies, tobacco, and lupine mosaic.

7. Necrosis. The browning and death of tissues is a characteristic effect of some viruses and may involve internal or

external tissues. External symptoms may be spots, streaks, or canker-like lesions, as in citrus psorosis. Internal symptoms may show a necrosis of the phloem as in phloem necrosis of elm, curly top of sugar beet, and net necrosis of potato.

Some virus diseases are actually the result of attack by two or more viruses at the same time with symptoms unlike those caused by either one alone. For example, streak of tomato is due to the latent virus of potato combined with tobacco mosaic, and rugose mosaic symptoms on potato are caused by a combination of two viruses attacking potatoes.

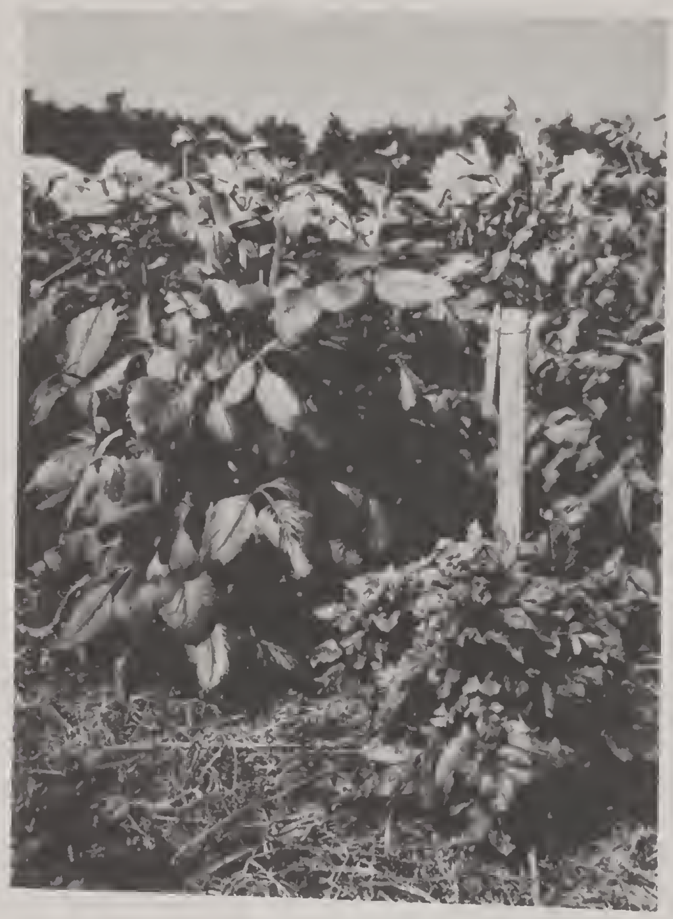


FIG. 164. Dahlia stunt caused by a virus. Compare with normal plants in the background.

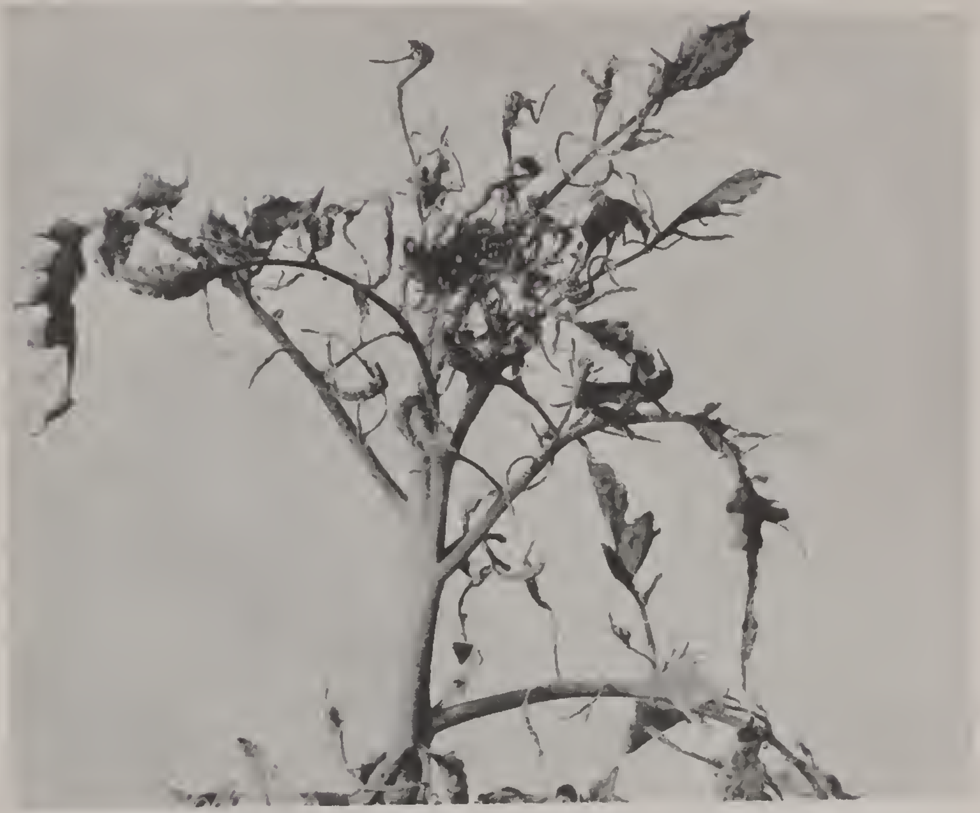


FIG. 165. Shoe-string symptoms on tomato infected with cucumber mosaic.

Transmission of Virus Diseases

Virus diseases may be transmitted by any one or more of the following means:

1. By mechanical means. This involves the actual application of the virus-containing sap to the suscept and is a common method of spreading the more highly infectious viruses such as tobacco, tomato, and cucumber mosaics. First diseased plants, then healthy ones are touched by pruning tools, grafting tools, or the hands. Tobacco smokers or chewers who smoke or expectorate near them may infect healthy plants.

2. By insects or other organisms. Insects (known as vectors) are responsible for the spread of the majority of virus diseases under natural conditions. In some cases the insects' mouth parts merely transfer the inoculum mechanically from

diseased to healthy plants, and in other cases the insect appears to be an intermediate host, as in the streak disease of maize and in aster yellows. In these two diseases the virus passes into the insect's digestive tract, and only after incubating for days or weeks and after multiplying can it be supplied to healthy plants through the saliva injected during feeding. Thereafter the insect and its progeny are continuous inoculating agents every time they feed. Insects most often responsible for transmitting virus diseases include sucking types such as aphids, leafhoppers, plant bugs, white flies, thrips; and chewing types such as grasshoppers, flea beetles, and cucumber beetles. Sometimes only a certain species of insect is able to transmit a definite virus under natural conditions. The plum leafhopper is the only insect that transmits peach yellows—grafting is the only other way in which it can be transmitted.

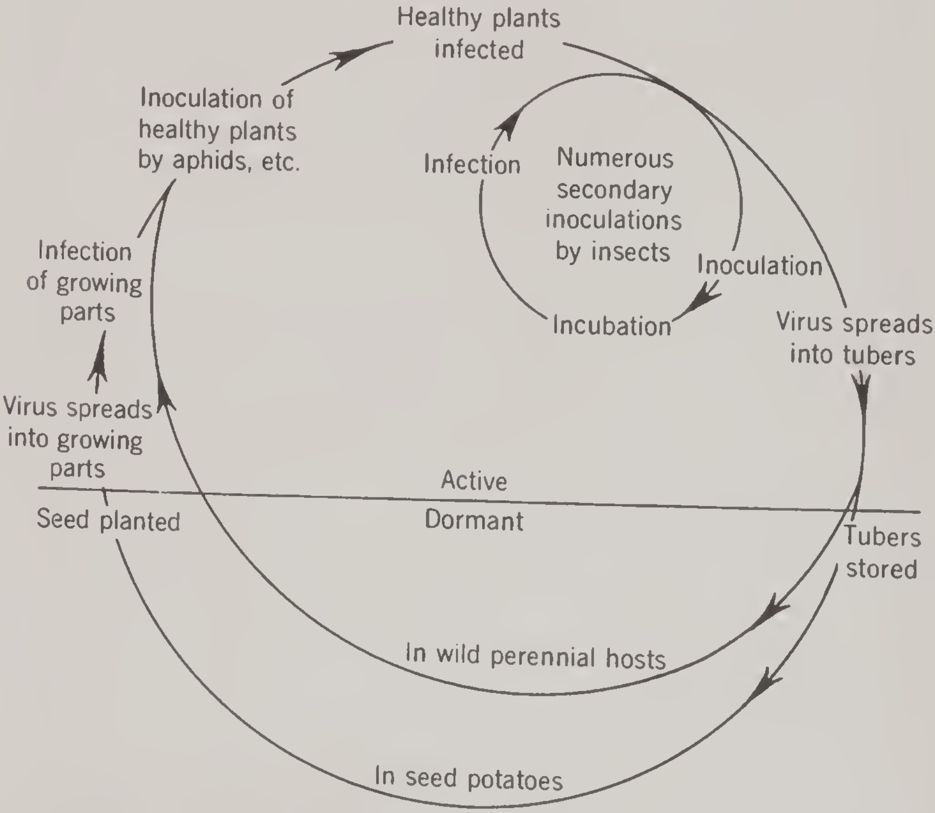

Healthy plants infected
Inoculation of healthy plants by aphids, etc.
Infection
Numerous secondary inoculations by insects
Inoculation
Incubation
Infection of growing parts
Virus spreads into tubers
Virus spreads into growing parts
Active
Dormant
Seed planted
Tubers stored
In wild perennial hosts
In seed potatoes

FIG. 166. Life history of viruses causing potato mosaics and other virus diseases of potatoes.

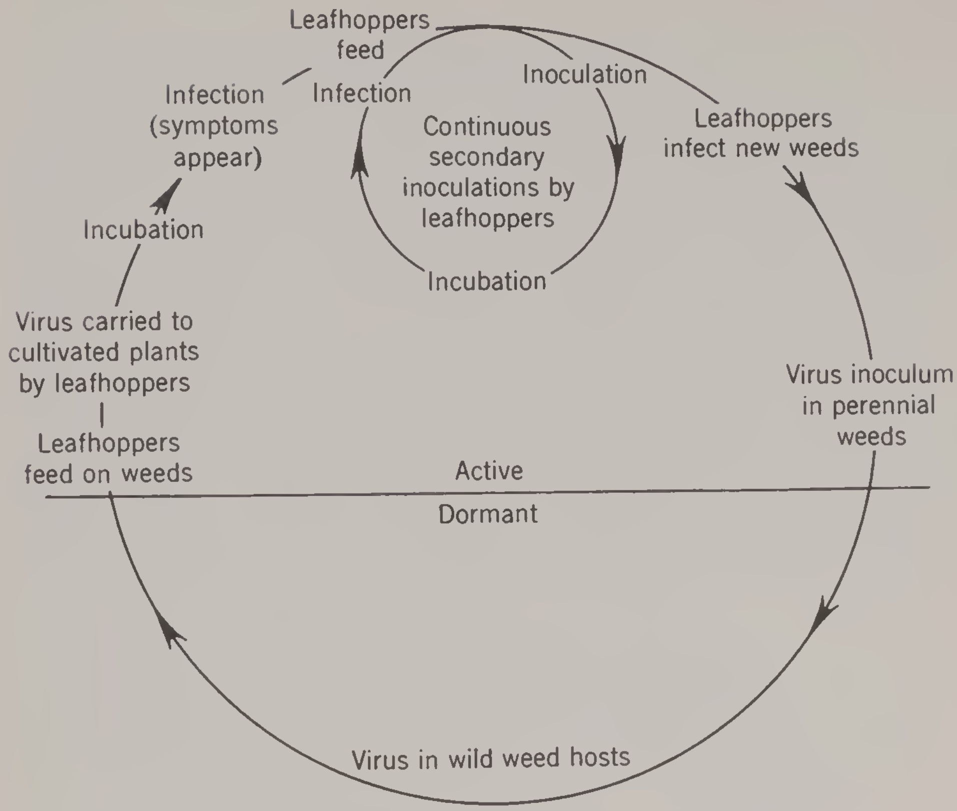

Leafhoppers feed
Infection
Inoculation
Infection (symptoms appear)
Continuous secondary inoculations by leafhoppers
Leafhoppers infect new weeds
Incubation
Incubation
Virus carried to cultivated plants by leafhoppers
Virus inoculum in perennial weeds
Leafhoppers feed on weeds
Active
Dormant
Virus in wild weed hosts

FIG. 167. Life history of the virus causing aster yellows.

3. By vegetative propagation. The use of grafting or budding stock from diseased plants is a common method of transmitting most viruses to healthy plants and frequently no other way of spreading the disease is known. Root contact may spread viruses among adjacent trees. This occurs in the scaly bark disease of citrus and in phloem necrosis of elm. Cuttings, bulbs, tubers, corms, and any vegetative part from a virus-diseased plant will establish the disease in the new plants.

4. By seed. Most viruses do not enter the seeds of plants attacked; however, some virus diseases such as the mosaics of legumes, lettuce, and petunia are known to be carried in the seed of infected plants and may gain a foothold in a garden by such means.

5. By soil. The only viruses known to be transmitted in the soil are wheat mosaic (which survives long enough to affect

the wheat crops following on that soil) and big vein of lettuce. The tobacco mosaic virus may be transmitted through infected tobacco refuse in the soil.

6. By pollen. Bean mosaic is the only known virus disease of economic importance that has been reported to be transferred to healthy bean plants through the medium of pollen from infected plants.

7. By dodder. Dodder is a parasitic vine that forms living bridges from plant to plant and thus transmits the virus.

For the life histories of two typical viruses see Figs. 166 and 167.

TABLE 32

SOME IMPORTANT DISEASES CAUSED BY VIRUSES

Name	Method of Transmission	Host Plants
Aster yellows	Leafhopper	Asters, celery, carrots, lettuce, marigold, cosmos, daisy fleabane, many ornamentals and weeds
Bean mosaic	Aphids (several), seed, pollen	Beans
Citrus psorosis or scaly bark	Budding and natural root grafts	Lemon, grapefruit, orange
Cucurbit mosaic	Aphids, cucumber beetles	Cucurbits, tobacco, tomato, celery, spinach, lilies, petunias, peppers, many others including weeds

Table 32 (Continued)

Name	Method of Transmission	Host Plants
Curly top	Beet leafhopper	Beets, beans, squash, spinach, alfalfa, tomato (western yellow blight), zinnia, and many others including weeds
False blossom	Leafhopper	Cranberry
Mosaic of crucifers	Cabbage and turnip aphids	Crucifers
Potato leaf roll	Aphids, infected seed tubers	Potato
Potato mosaic (mild)	Aphids, leafhoppers, infected seed tubers, contact	Potato
Pea mosaic	Infected seed, pea aphid	Peas, clover
Peach yellows and little peach	Plum leafhopper, grafting, budding	Peach, nectarine, almond, apricot, plum
Peach X-disease	Budding (insects?)	Peach, chokecherry, nectarine, sour cherry
Phloem necrosis of elm	Natural root grafting, leafhopper	American elm
Ring spot	Infected seed (insects?)	Dahlia, peony, petunia, tobacco, sweetclover
Spindle tuber	Infected seed, cutting knife, contact, aphids, fleabeetles, grasshoppers, Colorado potato beetle, etc.	Potato
Spotted wilt or yellow spot	Thrips	Tomato, pineapple, nicotiana, zinnia

Table 32 (Continued)

Name	Method of Transmission	Host Plants
Sugar cane mosaic	Infected stalk cuttings, corn aphid	Sugar cane, corn, wild and cultivated grasses
Tobacco mosaic	Handling infected plants, tools, tobacco smoking and chewing, green peach aphid	Tobacco, tomato, pepper, petunia, and others including weeds
Wheat mosaic	Contaminated soil	Wheat, rye, barley, grasses

PHYSIOPATHS AS CAUSES OF PLANT DISEASES

Probably more than 50 per cent of all plant troubles are due to improper environmental, nutritional, or physical conditions that may be referred to as physiopaths. The ailments caused by physiopaths are called physiogenic or non-infectious diseases. Various degrees of sickness, from mild disturbances affecting the plant or crop slightly to severe ailments resulting in loss of yield or death, may be caused by physiopaths. The severity of the trouble is determined by how far from the optimum any one or more of the disturbing factors vary. In many cases it has been noted that physiogenic diseases may make plants more susceptible to other diseases. Correction of the disturbing condition or factors generally results in recovery unless the effects have progressed too far.

DETERMINING THE CAUSE OF PHYSIOGENIC DISEASES. The signs or causes of physiogenic diseases are most elusive and often little understood or completely unrecognized. Their determination requires a knowledge of the cultural, nutritional, and environmental conditions that favor each crop or even each crop variety; for what may be best for one type of plant may harm or even kill another plant. Since rarely in nature do plants grow under fully optimum conditions, it follows that continual improvement may be obtained by finding out and reproducing as nearly as possible for each crop variety the ideal for such factors as the nutrient balance in the soil, physical character and composition of the soil, air and water balance in the soil, soil reaction (acidity or alkalinity), soil temperatures, air temperatures, air humidity, spacing of plants, cultivation, exposure and duration of exposure to sunlight, and numerous other factors that may influence the vigor and productiveness of given crops.

It is often difficult to distinguish between physiogenic diseases and those caused by living organisms and viruses, many of the symptoms being similar. Frequently the help of soil chemists and plant physiologists is necessary to track down the physiopath through chemical analysis of the plant

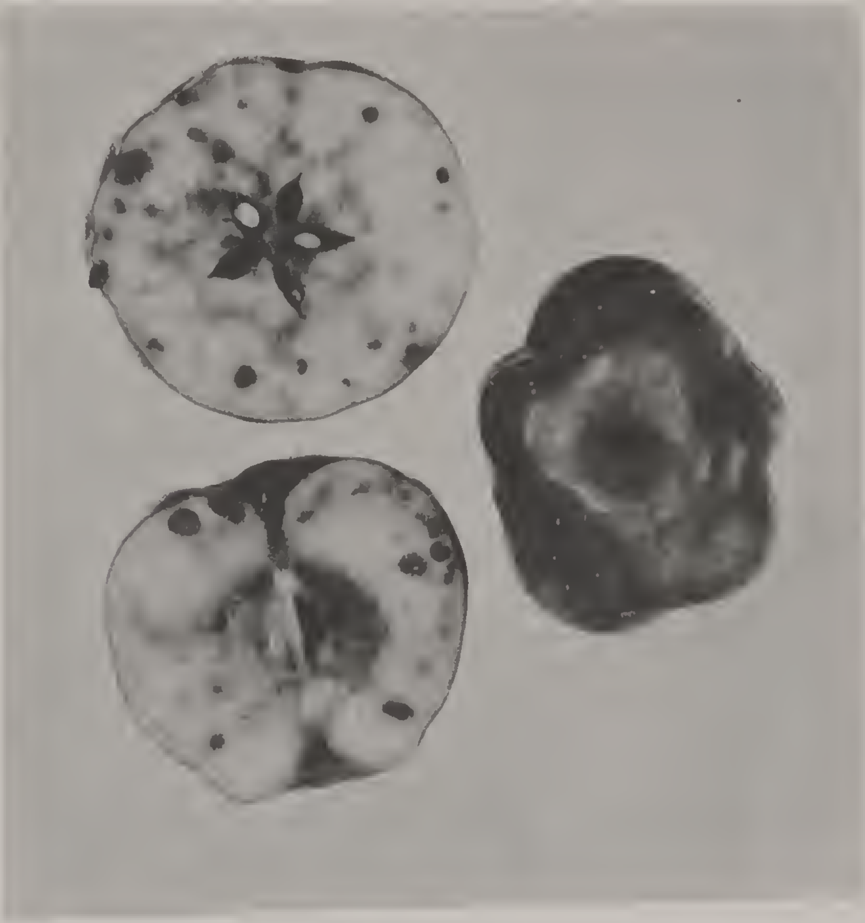


FIG. 168. Internal cork of apple caused by boron deficiency in the soil (courtesy A. B. Burrell, Cornell Univ.).

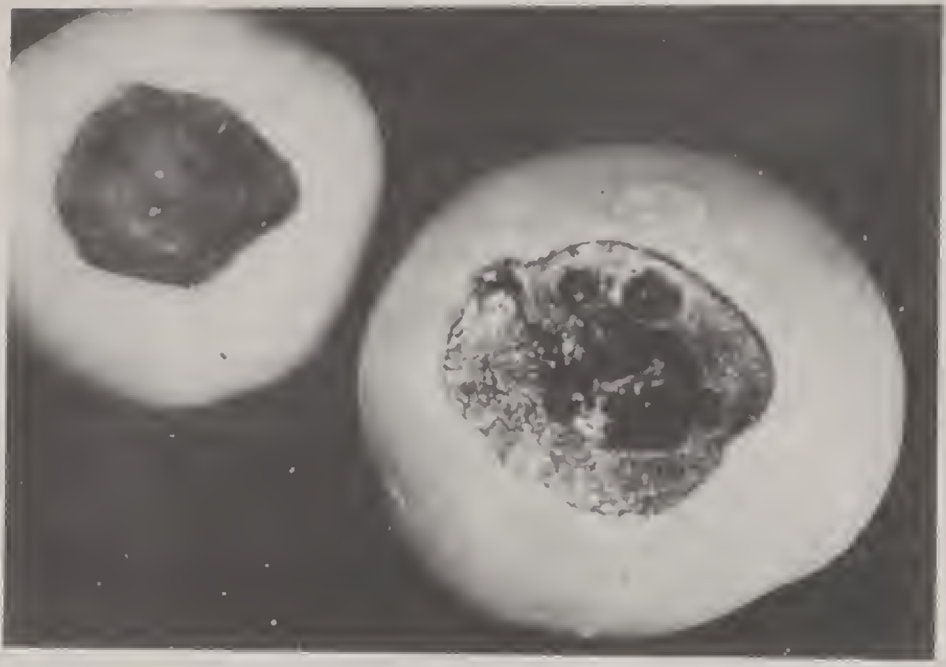


FIG. 169. Blossom-end rot of tomato caused by rapid changes in water content of soil.

tissue and the soil and by experimentation. At times even these methods have defied solution as to the cause of a physiogenic disease. However, the causes of many physiogenic diseases have been determined, and some of the most common ones are listed below.

1. Lack of necessary nutrients such as nitrogen, phosphorus, potassium, or magnesium salts. General symptoms: stunting and foliage discoloration.

2. Shortage or unavailability of minor elements such as zinc, manganese, boron, molybdenum, and copper. General symptoms: foliage discoloration and internal discoloration of fruits and vegetables (Fig. 168).

3. Excess or unbalanced condition of nutrients. Various symptoms: soft vegetative growth, delayed maturity, dropping of flowers, dwarfing, foliage discoloration, and "burning" of the roots.

4. Unfavorable alkalinity or acidity of the soil. May make certain nutrients unavailable. Symptoms: sickly yellow, dwarfed plants with poor or no root growth.

5. Unfavorable water content of soil—waterlogging. Symptoms: cracking of fruits and head vegetables, yellowing, wilting, defoliation, rolling of leaves, die-back, and death (Fig. 169).

6. Lack of soil aeration caused by raising soil grade under trees. Symptoms: slow death of trees with shallow root systems.

7. Unfavorable temperatures—high temperatures, frosts, freezing temperatures. Symptoms: foliage crinkling, fruit scorches, cankers, tipburn, "burning" of foliage, die-back.

8. Presence of poisonous gasses in air or soil. Symptoms: foliage discoloration, defoliation, curvatures (epinasty), stunting, death.

9. Toxic spray or dust materials. Symptoms: foliage discoloration, "burning," russeting of fruits, defoliation.

10. Toxic effects of certain decomposing plant residues in soil. Symptoms: root rots, decreased yields.

TABLE 33

SOME PLANT TROUBLES CAUSED BY PHYSIOPATHS

Plant Trouble	Causal Factor	Suscept
"Sand drown"	Magnesium shortage	Tobacco, cotton
"Bronzing"	Magnesium shortage	Citrus trees
Chlorosis	Magnesium shortage	Corn
Internal cork	Boron shortage	Apple
Brown heart	Boron shortage	Turnips, beets
Yellows	Boron shortage	Alfalfa
Gray speck	Manganese deficiency	Oats
Pahala blight	Manganese deficiency	Sugar cane
Chlorosis	Manganese deficiency	Ornamental trees, shrubs
Die-back	Copper deficiency	Citrus trees
"Rosette"	Zinc deficiency	Pecan, apple, pear
"Mottle leaf"	Zinc deficiency	Citrus
"Bronzing"	Zinc deficiency	Tung trees
Bud drop	Excess nitrogen plus cloudy weather	Roses, sweet peas, tomatoes
Cracking	Water excess after long dry period	Fruits and head vegetables

Table 33 (Continued)

Plant Trouble	Causal Factor	Suscept
Blossom-end rot	Extreme changes in water content of soil	Tomatoes
Die-back	Excessive transpiration	Evergreens
Sunscald cankers	Extreme temperature drops in winter or extreme heating in summer	Deciduous trees
Leaf crinkling and puckering	Frost hitting tender leaves just unfolding	Deciduous trees and shrubs
Epinasty (downward bending of leaf stems)	Ethylene gas injury	Tomatoes
Slow death of plants	Waterlogging of soil, poor drainage, raising soil level under trees, manufactured illuminating gas in soil	All dry-land trees and shrubs Shallow-rooted trees Trees, shrubs
Leaf and twig distortion and curling	Contact with 2,4-D weed killers	Susceptible plants
Root rots	Recently plowed under green cover crops	Strawberries

QUESTIONS FOR DISCUSSION

1. Why have plant troubles that were finally traced to viruses long been such a mystery?
2. Explain the nature of a virus.
3. Do you think virus diseases can be controlled by cultural methods?
4. What are the typical symptoms of a virus disease in a plant?
5. Why are virus diseases so difficult to control?
6. Why are sucking insects most often responsible for transmitting virus diseases?

7. Do seeds from a plant with a virus disease have the virus in them?

8. Why are virus diseases so important in potato growing?

9. Most of our certified seed potatoes come from colder northern areas. Why?

10. Why shouldn't one smoke in the presence of young tomato plants or handle them after smoking?

11. Should cuttings be made from a plant with a virus disease?

12. Can one tell from appearance alone whether or not a plant is free from a virus disease?

13. What connection is there between weeds and some of our common virus diseases?

14. Why are physiogenic diseases so prevalent under modern agricultural practices?

15. Do you think there would be less physiogenic troubles in crops planted on virgin land?

16. What is involved in determining the cause of a physiogenic disease?

17. Can a healthy looking plant actually be suffering from a physiogenic disease?

18. Plant nutrients may be present in a soil and still be unavailable to plants. Why?

19. How does a physiogenic trouble usually show up in a crop as compared to an insect or fungous disease outbreak?

20. What type of soil would tend to develop deficiencies most often? Least often?

21. Why is the pH of the soil so important to plant growth?

22. What may cause a soil to be waterlogged, with consequent plant injury?

23. What practices may lead to an unbalanced condition of soil nutrients?

24. Winter kill hits plants mainly in late winter and early spring. Why?

25. What may be done to prevent a tree from dying when it is necessary to raise the soil grade under it?

26. What locations are most subject to late spring frosts?

27. Why are newly transplanted trees susceptible to sunscald cankers?

28. What does it mean when young tomato seedlings in a home develop epinasty?

29. It may be harmful to plant a crop on land where a cover crop was just plowed under. Why?

Chapter 17

THE CONTROL OF PLANT DISEASES

The organisms causing plant diseases, like all other organisms, are either encouraged or discouraged by natural factors such as temperature, moisture, antagonistic organisms, and host plant abundance, which play a major part in determining whether a disease will be absent, mild, or epiphytotic in any given area. The effect of these factors on potentially devastating disease-producing organisms has been discussed previously in Chapter 15. Man through necessity and with the aid of research has also found ways to limit the prevalence of plant diseases.

There are five main methods of tackling the control of plant diseases:

1. Exclusion, or the prevention as far as practicable, of the entrance and establishment of a disease-producing organism in uninfested areas.
2. Eradication, or the removal, elimination, or destruction of a disease-producing organism in a given area.
3. Protection, or the placing of some effective barrier, chemical or physical, between susceptible organs of the host plant and the inoculum of the disease-producing organism so that the pathogene will be destroyed before infection sets in. Protection may also include the prevention of inoculum formation or the destruction of the inoculum before incubation is completed.
4. Immunization, or the rendering of plants or crops immune, resistant, or tolerant to injury from certain disease-producing organisms or factors.
5. Chemotherapy, or the curing of diseased plants through internal chemical treatment.

Virus Disease Control

Virus disease control is based on the following specific procedures:

1. Control and elimination of insects that may carry and spread the virus.
2. Screening of plants from insect vectors.
3. Removal and destruction of infected plants or trees.

4. Selection of only healthy, uninfected stock as a source of cuttings or of budding and grafting material.
5. Production and use of certified seed if virus is seed-borne.
6. Destruction of susceptible weed hosts.
7. Selection and breeding of resistant varieties.
8. Chemical treatments to destroy or inhibit the virus (chemotherapy).

NON-CHEMICAL METHODS OF DISEASE CONTROL

The non-chemical methods of disease control closely parallel those previously covered under insect control. They include Federal and state quarantines, inspection and certification at point or origin, sanitary measures, planting and cultural practices, and selection and propagation of disease-resistant varieties.

Sanitary Measures

These consist chiefly of the following desirable practices:

1. Removal and destruction of diseased fruit, storage organs, leaves, other plant parts, or the whole plant or crop if it is beyond salvage.
2. Removal, destruction, or avoidance of proximity of intermediate hosts of rust diseases.
3. Removal and destruction of spore fruits such as bracket fungi, toadstools, and sporophores.
4. Treatment of wounds or lesions (such as pruning cuts, cankers, and breaks) to promote rapid healing.
5. Burning or destruction of rank weed growth and other uncultivated plants that may harbor diseases.
6. Avoidance of contaminated manures that may carry and spread soil-borne pathogenes such as carotovorus soft rot.
7. Selection of disease-free seed or planting stock. This may be accomplished by obtaining seed from uninfected areas, for example, bean seed from Idaho to avoid bacterial blight and anthracnose; cabbage seed from Puget Sound to avoid black rot; and potato seed from Maine and Canada to avoid virus diseases. Where this is not possible, seed from specially protected seed blocks or from blocks where careful inspection and roguing of diseased plants have been carried

out should be utilized. Where seed or planting stock is infected, it is sometimes possible to clean out the organisms by selection, as in the case of nursery stock, bulbs, corns, or tubers, where obviously infected material may be discarded.

8. Use of certified seed or planting stock. When seed or planting stock is certified, it means that it was taken from plots that were free or nearly free of seed-borne pathogenes according to the rules of certification of each state. Generally these rules allow for only very small amounts of disease in the seed crop, or, for some diseases, none at all. The crops are inspected and rogued, if necessary, a few times during the growing season by qualified personnel. If all conditions for certification are met, the inspectors issue certification labels.

Planting and Cultural Practices

These include practices such as:

1. Crop rotation. Disease-producing organisms as well as insects may be starved out but perhaps not as readily in most cases.
2. Destruction of weeds in cultivated areas. Weeds may compete with and weaken crop plants or may harbor certain diseases.
3. Use of corrective fertilizers or avoidance of too heavy applications of certain plant nutrients that favor disease. Fire blight of pear is favored by heavy applications of nitrogenous fertilizers.
4. Time, rate, and methods of planting should be those shown by experience to be best for the crop in question.
5. Regulated watering or overhead irrigation during favorable drying conditions. Damp, moist conditions for 12 hours or more are conducive to disease outbreaks.
6. Selection of a suitable planting site. Wet or poorly drained soils, poor soils, and locations subject to late spring frosts and early fall frosts should be avoided.
7. Avoidance of mechanical injuries to crops during harvesting and storage, since these injuries furnish easy access for disease-producing organisms.

Selection and Breeding of Disease-Resistant Varieties

In the long run selection and breeding of disease-resistant varieties offer the best and cheapest methods of disease control. Man has discovered that nature in her own slow and gradual way has created many plant varieties that are immune or resistant to certain diseases which quickly overwhelm their more susceptible brethren. Immunity or resistance in plants may be due to: (1) a chemical constituent that is toxic to the parasite, for example, red pigment in the red onion scales that makes the red onion immune to the smudge disease; or (2) a physical barrier such as heavy pubescence or extra thick cuticula that prevents infection from occurring. Man has used this knowledge to hunt or watch for and propagate these disease-escaping varieties.

Development of more resistant varieties may be hastened by crossing already resistant varieties with susceptible varieties in the hope that the resistant factor may be combined with other good characteristics in one or more of the progeny. By such selection, by hybridizing, and by breeding, crops immune or resistant to certain infectious diseases or adverse environmental factors may be produced. Yellows-resistant (fusarium wilt-resistant) cabbage, rust- and smut-resistant cereals, wilt-resistant cotton, powdery mildew-resistant melons, downy mildew-resistant grapes, and blight-resistant chestnut trees are excellent examples of the value of this method of disease control.

Breeding for resistance, however, may lead to other dangers, as has often been discovered. Increased virulence of the disease-producing organism may be promoted by increased host resistance, since only the most virulent of the organisms may breed on more resistant hosts. Breeding for resistance to one disease may produce a plant variety more susceptible to other diseases; or new strains of the disease-producing organism to which the plants are not resistant may be present or may arise. Many disease-resistant varieties of fruits, vegetables, cereals, flowers, and field crops are available to growers and many more are continuously being introduced. These varieties should be adopted as soon as they are proven suitable; there is no better method of disease control.

HOW CHEMICALS ARE USED IN THE CONTROL OF PLANT DISEASES

Chemicals used to control or prevent plant diseases caused by fungi or bacteria are called fungicides. Fungicides may be used in several ways in disease control, depending on the chemical, the nature of the disease, and the nature of the plant attacked:

1. They may be used as preventive agents to form a toxic barrier between the inoculum and the host tissue, to inhibit the production of inoculum, or to destroy the inoculum before it reaches the infection court.
2. They may be used as eradicating agents to destroy the disease-producing organism or its inoculum on the host tissue or in the soil.
3. They may be used as curatives or therapeutic agents to destroy the disease-producing organisms within the plant tissues, halt their growth, or inhibit the development of their toxins or counteract them.
4. They may be used as prophylactic agents to immunize plants against disease.

Fungicides may be useful in any one or more of the above ways, but since it is much easier to protect plants from disease rather than to cure disease, chemicals are best in the form of protectants. Protective chemicals may act to prevent sporulation and thus to reduce or eliminate the inoculum necessary for the spread of a disease; they may also prevent spores from completing their germination or incubation stage so that no infection ensues. Eradicant chemicals which in a broad sense may also be considered protectants are used to destroy disease-producing organisms or their inoculum in the soil, in dead plant organs, or on living plant tissue. When used to treat soil or seed, they are usually referred to as disinfectants or disinfestants.

CHEMICAL TREATMENTS FOR DISEASE CONTROL

When weather or other environmental conditions favor destructive outbreaks of plant diseases, fungicides should be used to supplement control methods previously discussed. The chemical treatments for disease control may be divided into three groups: (1) seed treatments, (2) soil treatments, and (3) plant treatments. Plant treatments are discussed in Chapter 18. The nature of the disease will determine whether any one or more of the treatments should be used in any particular case.

Chemical Soil Treatments

Many plant pathogenes are soil-borne, with the inoculum remaining viable for 1 or more years. The application of chemicals to the soil is one of the methods for control or eradication of the soil-borne organisms, the chemicals or agents being generally referred to as soil disinfestants. Soil disinfestants are widely used to destroy pathogenic soil-borne organisms in greenhouses, cold frames, hotbeds, seedbeds, and small plots. To date their application to large areas has been considered too costly, but with the development of cheaper chemicals and more efficient methods of application large-scale operations may be economical where great crop losses would otherwise result. The aim in chemical soil treatments is to destroy only the dangerous pathogenes (soil pasteurization) and not to harm the beneficial organisms or the soil. Treated soil should never be placed into contaminated containers, because this defeats the purpose of the treatment.

DISINFESTATION WITH HEAT. Soils may be disinfested of fungi and bacteria either by heat or by chemicals. Steam is one of the most effective methods. It may be applied through built-in tiles or pipes in permanent plant beds, by an inverted steam pan for confining the steam to a definite area for a given time, by covering beds with rubberized cloth or Sisalcraft paper and releasing steam underneath the cover, or in a steam-sterilizing chamber specially built for flats, pots, or soils. Efficient steam sterilization is accomplished in the time it takes to bake a medium-sized potato buried a few inches in the soil. Dry heat applied to soils in enclosed chambers such as ovens, so that the soil is heated to 160° F., will give adequate pasteurization. These heat treatments also control soil insects and nematode worms.

DISINFESTATION WITH CHEMICALS. A few of the chemicals used in soil disinfestation of pathogenes are also effective in insect and nematode worm control and have been discussed previously. The chemicals useful against soil-borne pathogenes are the fumigants chloropicrin, formaldehyde, and methyl bromide; the inorganic mercury compounds corrosive sublimate and calomel; and the organic compounds hydroxymercuri chlorophenol (Semesan), phenolmercuri triethanol ammonium lactate (Puraturf), phenol amino cadmium dilactate (Puraturf 177), phenylmercuric acetate (PMAS), and tetramethyl thiuram disulfide (thiram).

The chemicals that vaporize readily and leave no harmful residue in the soil are most effective in soil disinfestation because chemical vapors tend to permeate the soil in all directions much better than materials in suspension or solution. Formaldehyde or chloropicrin are the two fumigants most practical for soil disinfestation. Methyl bromide is more effective as an insecticide and a nemacide than as a fungicide but may be used under confined conditions for 24 hours at high concentrations (4 pounds per 100 square feet or cubic feet) to destroy disease-producing organisms. Fungicidal fumigants are not effective when soil temperatures are low or when the soil is too wet or too dry. Both the inorganic mercury compounds and the organic compounds mentioned above are mainly soil-surface disinfestants to destroy soil organisms causing turf diseases and post-emergence damping-off.

Formaldehyde. This material is usually purchased as a 40 per cent solution of the gas formalin in water or as a dust containing 15 per cent formalin. It is one of the most common soil fungicides in greenhouses and in small plots. It is effective against damping-off fungi as well as against some others but has little effect on soil insects and on nematode worms. For a soil fungicide, the 40 per cent solution is diluted 1 to 50 by volume and is applied to the prepared soil bed at the rate of about 2 quarts per square foot. A tarpaulin or wet sacks should be placed over the treated area for 24 hours, and the odor should be gone before stock or seed is planted. For treatment of small amounts of soil in pots or flats, 2 1/2 tablespoonfuls of commercial formalin are mixed with 1 cup of water and the solution is sprinkled over and thoroughly mixed with each bushel of soil. The treated soil is then placed in the pots or flats and covered over for a day before the seeds are sown, after which the soil should be thoroughly watered. This treatment disinfests seeds, soil, and container, all in one operation.

Chemical Seed Treatments

Chemicals may be applied to seeds for either one or both of the following reasons: (1) to eradicate disease-producing organisms carried with, on, or in seeds and (2) to protect seeds from soil-borne pathogenes that cause seed rots and damping-off. Many of the disease-producing bacteria and the fungi that cause blights, spots, and rots are carried on or in seeds, roots, bulbs, tubers, corms, or other seed stock that is purchased by growers. It is possible to waylay these hitch-hiking organisms before they are introduced into the fields, if we are aware of or suspect their presence on newly purchased seed or planting stock. This may be done by various treatments aimed at the destruction of the disease-producing organisms with the least injury to the seed or planting stock.

When seeds or planting stock are known to be selected from disease-free plants, there is little need for seed treatments; however, certified seed (especially seed potatoes) may require additional treatments for other diseases that certification does not cover. When uncertified seed is offered for sale, the seed growers alone are in a position to know whether their seed needs treatment, and they may make it. Often it is left up to the purchaser as a means of insurance to treat seed that may carry a seed-borne disease. Some seed-borne pathogenes such as those that cause virus diseases in potatoes and dahlias and bean anthracnose are not susceptible to seed treatment, and other means of control must be used.

SEED DISINFECTION. These treatments are made to kill disease-producing organisms on or within infected seed. Disinfection is generally accomplished by dipping the seed or planting stock in hot water or in chemical solutions. The aim is to kill the pathogene without impairing the viability of the seeds; this usually requires carefully controlled conditions.

Hot Water Dip. This method is used for internal seed-borne pathogenes shortly before planting, since the organisms can be reached and destroyed only by heat. The seed is placed in loose cheesecloth bags, thoroughly wetted or soaked in warm water (110° F.), and then placed in water at the required temperature for the required time. After this treatment the seed is immediately cooled in cold water, dried, and coated with a protective dust, if necessary, before it is planted.

Only fresh seed should be used; in this treatment old seed is easily injured. The following diseases may be controlled by hot water dips:

Loose smut and nematode disease of wheat (129° F., 10 min.).

Brown loose smut of barley (128° F., 13 min.).

Late blight of celery (118° F., 18 min.).

Black leg of cabbage (122° F., 30 min.).

Black leg of cauliflower (122° F., 15-20 min.).

Bacterial canker of tomato (122° F., 25 min.).

Root rot of aloe (115° F., 30 min.).

Corrosive Sublimate Dip. This treatment is commonly used as a surface disinfectant for seeds, roots, tubers, corms, and bulbs. Because of the poisonous nature of the material, it should be used with extreme care and discarded carefully. Only non-metallic containers should be used, since the chemical is highly corrosive. The usual dilution is 1 to 1000 or one 8-grain tablet per pint of water (1 ounce to 7 1/2 gallons of water). The chemical should be dissolved in a small amount of hot water before it is added to main solution, which should be at about room temperature (70° F.). The seed or planting stock is placed in cheesecloth bags, soaked for the required time (5 minutes for cucurbits), thoroughly rinsed with fresh water, and treated with a protectant, if necessary, before planting. Other chemicals used as dips are listed in Table 34. These chemicals are not generally rinsed off after dipping.

Roots, rhizomes, tubers, corms, and bulbs for use in propagation often require chemical disinfection. The parts to be treated should be cleaned, all rotted spots cut out, and the parts allowed to dry out for a few days. They are then dipped for the required time in the recommended solution. Potato tubers should be treated, even though certified, before they are cut up into seed pieces.

Disinfection by Aging

In some cases seed-borne pathogenes die off before the seeds lose their viability. Delaying the use of seed in these cases may then be a method of disinfecting them. Aging seed for 2 years destroys the fungus causing cotton anthracnose, squash foot rot, and bacterial spot of cowpea. Three-year-old celery seed is free of the inoculum causing septoria leaf spot.

Protective Seed Treatments

Many disease-producing organisms that rot seeds or the bases of seedlings are nearly always present in garden soils. When conditions are favorable for their development, they are the chief cause of seed not sprouting or of poor stands of seedlings. Seed under glass and early spring-planted seed are especially subject to attack. Protection from these soil-borne organisms may be obtained by dipping the seeds in a chemical solution or suspension, by coating them with a dry chemical dust, or by coating them with a chemically treated film by pelleting or by the slurry method. Many seed-protecting chemicals are also used as surface disinfestants on some seeds. Certified seeds still require seed protectants; disinfected seed requires protectants if the disinfectant is not also a protectant.

In the dip method the seeds are dipped into a solution or suspension, and the residue is allowed to dry on them before planting. Formaldehyde, calomel, yellow oxide of mercury, and Semesan Bel are examples of fungicides that may be used in this fashion. In the dust treatment the seeds are shaken up with the dry chemical so that each seed is protected by a thin, even film of the fungicide. The amount of dust generally varies from 1/10 to 1/2 per cent of the weight of the seed treated.

Small seed packages are best treated by slitting them open and placing in them a pinch of dust on the end of a knife. The seeds in the package should then be shaken vigorously for a few minutes so that they obtain an even dust coating. For larger amounts of seeds a covered pint or quart mason jar or special mixing equipment can be utilized. Care should be taken not to get too heavy a coating of dust on the seeds, because this may result in delayed germination or injury. All excess dust should be screened off from the seed before it is planted.

Most flower seeds tend to be retarded in germination or harmed by some chemical dust treatments. For them, soil disinfestation alone generally gives the best results against seed rots and damping-off. Seed treatment is common for many vegetables as a means of protecting them before emergence against disease-producing organisms. Some vegetable seed such as radishes and smooth-seeded peas are very resistant to decay, whereas beans, corn, and cucurbits are very subject to it. Cabbage and cauliflower when sown early in the spring are also subject to seed decay. These vegetables, along with beets, tomatoes, and peppers, usually give greatly improved stands when they are treated with seed protectants.

In pelleting, a quick-drying plastic such as methyl cellulose (Methocel) is impregnated with the seed-treating fungicide, and the seed is coated with the mixture by dipping or spraying. Higher dosages of seed protectants are possible by this method, because only a certain amount of dust will normally adhere to seeds. In the slurry method (see page 464) for description of equipment and process) the seed is mixed with a heavy suspension of the fungicide in wettable form so that on drying each seed has a protective coat of the chemical. This method has the advantage over dust coating in that it eliminates the hazard of harmful dust in the air and allows for more even and accurate dosages; thus better results may be obtained.

There are many seed protectants on the market—some are injurious to certain varieties of seeds; others are more effective for particular diseases on certain seeds or in certain soils. One should pick the seed protectant recommended for the crop and should follow directions carefully. Many of the chemicals used in seed protection are also valuable in preventing post-emergence damping-off when the chemicals are dusted lightly over the tops of the rows before seedling emergence takes place.

TABLE 34

CHEMICALS USED IN SEED TREATMENTS

Chemical Name	Trade or Common Name	Principal Uses
	Copper Compounds	
Red copper oxide	Red Cuprocide	Coats seeds of sugar beets, vegetables except crucifers, water-sown rice

Table 34 (Continued)

Chemical Name	Trade or Common Name	Principal Uses
Copper carbonate	Coppercarb, Carbo	Cereal-seed treatments for smuts
Zinc oxide	Vasco-4	Vegetable seeds except peas
	Inorganic Mercury Compounds	
Mercuric chloride	Corrosive sublimate	Dip for seeds, tubers, corms, bulbs
Mercurous chloride	Calomel	Dip or dust for seed
Yellow oxide of mercury	.....	Dip for potatoes (1 lb. in 30 gal. water)
	Organic Mercury Compounds	
Ethylmercuric phosphate	New Improved Ceresan	Seeds of cereals, cotton, sugar beets, peas, flax, bulbs
Ethylmercuric phosphate	Semesan Jr.	Corn, flower bulbs
Ethylmercuric chloride	Ceresan 2%	Cotton, peas, flower bulbs, seed grains
Ethylmercuric -p-toluene sulfanilide	DuBay 1451, 1452, Ceresan-M, GGG (slurry)	Same as Ceresan 2% but less toxic
Hydroxymercuri chlorophenol	Semesan	Vegetable seeds, bulbs
Hydroxymercuri chlorophenol + hydroxymercuri nitrophenol	Semesan Bel	Dip for tubers and roots

Table 34 (Continued)

Chemical Name	Trade or Common Name	Principal Uses
Mercuric phenol cyanamide + cadmium oxide	Barbak C	Corn seed
Phenylmercuric acetate	Mersolite	Cotton seed
Miscellaneous Organic Compounds		
Zinc trichlorophenate	Dow 9B	Cotton, peas, corn, bulb dip
Formaldehyde	Formol, formalin	Seed, tuber, bulb dip
Tetrachloro-p-benzoquinone	Spergon	Vegetables, flowers, cereals except oats and barley, legumes
2,3-dichloro-1,4-naphthoquinone	Phygon	Cereals except oats and barley, peanuts, flax, beets, spinach
Tetramethyl thiuram disulfide	Arasan	Cereals except oats and barley, peanuts, vegetables, flowers, lily bulbs
Disodium ethylene bis-dithiocarbamate	Dithane D-14	Dip for potatoes (1 pt. in 30 gal. water)
Ferric dimethyl dithiocarbamate	Ferbam, Fermate, Karbam	Vegetables, sorghum, gladiolus, bulbs, woody cuttings
n-trichloromethylthio tetrahydrophthalimide	Orthocide 406	Vegetable seeds

QUESTIONS FOR DISCUSSION

1. Can the principle of exclusion be used in combating air-borne disease-producing organisms?
2. Is it possible to eradicate a disease in any given area?
3. Why is chemical protection the most widely used method of disease control to date?
4. Which of the methods of disease control is the most promising from the standpoint of efficiency and effective results?
5. What has limited the progress of plant chemotherapy?
6. Is there any assurance that a plant variety that is immune to a certain disease will stay immune to that disease?
7. Why can't virus diseases be controlled once plants are infected?
8. Should non-chemical methods of disease control be neglected in favor of effective chemical methods if they are available?
9. Why should wounds or lesions in perennial woody plants be protected by special tree paints?
10. Does the use of certified seed insure a disease-free crop?
11. In what ways does crop rotation help control plant diseases?
12. How would one proceed to try to develop a plant variety resistant to a certain disease?
13. Is breeding for disease resistance a cure-all once resistance has been obtained?
14. How may chemicals be used in the control of plant diseases?
15. What types of diseases may be prevented by chemical soil treatments?
16. What has held back the use of soil disinfestation on large areas?
17. Why do fumigants make more effective soil disinfestants than chemical solutions or suspensions?
18. Why is chemical seed treatment considered as a sort of crop insurance?
19. Does the fact that seed has been treated by a seed company mean that the seed was taken from fields heavily infested with certain seed-borne organisms?

20. Does seed treatment alone insure a crop free from the pathogenes that are carried on or in the seed?

21. One-year-old celery seed may be heavily infested with the spores of septoria leaf spot, but three-year-old seed generally does not carry the pathogenes. Can you offer any explanation for this?

22. Under what conditions is seed disinfection necessary? Seed protection? Both?

23. Arasan has been found more effective to protect seed from damping-off in heavily infested soils, whereas Spergon gave better results in lightly infested soils. Can you give any reasons for this?

24. What may be some of the reasons for poor stands of seedlings?

25. What is the best procedure for controlling an insect-borne virus disease? A seed-borne virus disease?

26. Is an introduced soil-borne disease more apt to go on a rampage in a sterilized soil or in an unsterilized soil? Explain your answer.

Chapter 18

PLANT TREATMENTS FOR DISEASE CONTROL

Plant treatments by chemicals in the form of fungicidal sprays, dusts, spray-dust combinations, mists, or aerosols are made on growing crops or on crop residues either to prevent the appearance or spread of diseases or to destroy the disease-causing organisms already present or both. This type of treatment is essential for plant protection from air-borne pathogenes and is also useful in controlling many seed- and soil-borne pathogenes that spread externally to the upper parts of plants. Chemical prophylaxis and therapy that deal with the application of chemicals internally to prevent or destroy diseased conditions may also be considered under this heading. Bacterial diseases are not as easily controlled as fungous diseases by sprays, dusts, or aerosols, because of the way inoculation generally takes place and because incubation takes place within the host's tissues.

The timed application to plants of chemicals for both insect and disease control forms a definite part of general cultural practices for many of our crops. It is well to remember, however, that no matter how effective the chemical is it may be worthless if applications are not properly timed or applied. Equipment for the application of insecticides, fungicides, and weed killers is discussed in Chapters 26, 27, and 28.

The chemicals for disease prevention and control on foliage or fruits may be divided into three groups: the copper compounds, the sulfur compounds, and the new organic compounds.

THE COPPER COMPOUNDS

These compounds are relatively non-toxic to man and animals but are corrosive to metals. They are useful as protectants, not as eradicants. They may be divided into (1) Bordeaux mixture and (2) the "fixed" or "low-soluble" types of copper fungicides.

BORDEAUX MIXTURE. This compound actually started the impetus in the development of modern chemical disease control. It is a chemical combination of copper sulfate (bluestone or blue vitriol) and hydrated lime. The old method of making it is to hang 50 pounds of the large crystals within a sack in 50 gallons of water in a wooden barrel until the crystals dissolve. Each gallon of solution then contains 1 pound of copper sulfate. The required amount of this solution is then poured into the nearly filled spray tank with the agitator running, a thin, paste-like mixture of the lime is added, and the tank is filled with water. A sky-blue suspension forms; this is Bordeaux mixture. Some of the more common formulas are 8-4-100, 6-4-100, and 4-4-100 (pounds of copper sulfate-pounds of hydrated lime-gallons of water). The weaker solutions are for plants that tend to be sensitive to copper injury. Care should be taken to use only fresh, finely ground hydrated lime. Once formed, Bordeaux mixture should be applied at once; its effectiveness is reduced if it is allowed to stand for some time before it is applied.

A simpler, easier, and newer method of making Bordeaux mixture is to use the powdered, superfine, or sugar-like grade of copper sulfate which may be washed through the strainer with the agitator running as the tank is being filled. The necessary hydrated lime may also be washed through the screen or puddled in a bucket and then washed through. Freshly made Bordeaux has excellent adhesive power once it has dried on foliage. Commercial copper fungicides for dilution with water are obtainable on the market, but they are inferior to home-made Bordeaux, because they adhere less tenaciously.

Bordeaux mixture may be formed on plants by applying a 20-80 monohydrated copper sulfate-hydrated lime dust in which 20 pounds of the monohydrated copper sulfate is mixed with 80 pounds of lime. When this dust is applied in the presence of moisture or dew on the foliage, a layer of Bordeaux forms. Plants that remain dry for a few days after dusting are not protected, because the lime becomes carbonated and insoluble, and no Bordeaux can be formed.

Both copper and lime used in sprays may be much more injurious to plants than was formerly realized. Copper injury may cause paling of leaf margins, dwarfing, brittleness, and spotting. Lime injury usually results in brittleness, dwarfing, leaf deformation, or discoloration on lime-sensitive plants such as cucurbits, young tomato plants, and strawberries.

THE FIXED COPPERS. To avoid the combination of both copper and lime injury to sensitive plants the “fixed” or “low-soluble” coppers have come into wide use in recent years. These are basic or normal copper salts that go into suspension in water. They are marketed under trade names by many companies, but basically they consist of chemicals such as yellow copper oxide, copper oxychloride, tribasic copper sulfate, and copper silicate. Some are safer to use than Bordeaux but do not give as satisfactory disease control, mainly because they do not have the residual adhesiveness of Bordeaux. The fixed coppers may be applied in either spray or dust form. Dusts are generally made up to contain 7 per cent actual copper and do not deteriorate on dry plants like copper-lime dust.

TABLE 35

SOME COPPER FUNGICIDES FOR USE ON PLANTS

Chemical	Common or Trade Names	Uses
Yellow copper oxide	Yellow Cuprocide	Damping off, some vegetable diseases
Copper sulfate and lime	Bordeaux mixture	Late blight of potatoes, many vegetable and some fruit diseases
Copper cadmium oxychloride	Copper A Compound	Vegetables, small fruits, flowers
Copper oxychloride	Cupro-K	Cherry leaf spot, small fruits, vegetables
Copper oxychloride sulfate	COCS	Cherry leaf spot, fruits, vegetables
Tribasic copper	Tribasic, Basicop	Ornamentals, small fruits, vegetables
Copper sulfate + magnesium hydrate	Bordow	Cherry leaf spot, vegetable diseases

THE SULFUR COMPOUNDS

Sulfurs have been mentioned previously as insecticides and acaricides, but their chief use is as fungicidal sprays or dusts on fruits, ornamentals, and some tolerant vegetables such as beans. They are classed as lime-sulfur, wettable sulfurs, and sulfur dusts, and are all available under numerous trade names. Sulfurs tend to be harmful to many vegetables and so are not usually applied in vegetable gardens. They are valuable against powdery mildews and a number of other diseases of fruits, flowers, and ornamentals. All the sulfurs are protectants, but lime-sulfur, in addition, is an eradicant for some diseases such as apple scab. Sulfurs when applied in hot weather tend to be harmful to foliage and applications should generally be discontinued when the temperature reaches 80° F.

LIME-SULFUR. Liquid lime-sulfur is made by boiling quicklime and sulfur in water to form an amber-colored liquid of 32° Baumé specific gravity. It was once widespread as a fungicide on fruits, but, because it is disagreeable to use and harmful to the foliage especially when temperatures are high, it is gradually being replaced by other types of sulfurs and by the new organic fungicides. It is still used by many fruit growers that wish to "burn out" apple scab under conditions of heavy infestation. Dry lime-sulfur is a powdered form of liquid lime-sulfur and has similar properties when diluted with water as a spray.

WETTABLE SULFURS. These are at present widely used as substitutes for lime-sulfur because they are safer on foliage, but they are valuable only as protectants. They are finely divided sulfurs treated with wetting agents to allow them to form a suspension in water. Experiments have shown that, the more finely divided the sulfur particles are, the better is the protection obtained. The so-called micronized sulfurs generally produce the best results. Flotation sulfur is a very finely divided sulfur paste made as a by-product of gas manufacture.

SULFUR DUSTS. These are made from finely divided elemental sulfur and may be dusted on plants in undiluted form. Unless repeated often or used with a spray-duster they do not give as good protection as sprays, since they are readily washed off by rains. Sulfur is not poisonous, but the dust may cause a severe eye inflammation, so protective goggles should be worn when the dust is applied. Sulfur may be heated to produce sulfur vapors that are useful in disease control (powdery mildew) in greenhouses; but it should never be burned, because sulfur dioxide which is very injurious to plants is given off.

Sulfurs are compatible with many insecticides and fungicides including the newer organic ones but should never be used in combination with oils or within 3 weeks preceding or following oil sprays, because severe foliage injury may result. There is some question as to its compatibility with parathion. See compatibility chart, Table 50.

THE ORGANIC FUNGICIDES

Many new organic compounds with fungicidal properties have recently been discovered. For some diseases they are much more effective than the older fungicides and show a definite specificity. Because of this specificity it is important to select the best fungicide to do the job (see Table 36 for list and chief uses).

The majority of the newer organics may be divided into the dinitro compounds, the dithiocarbamic acid derivatives, the phenyl-mercury compounds, the quinone derivatives, the quinolinolate derivatives, and the glyoxalidines.

THE DINITRO COMPOUNDS. These have been discussed previously as dormant insecticides; at the same dilutions they are also useful as dormant sprays in the eradication of spore-producing structures in dead leaves and in lesions on trees and shrubs. They are valuable in ground treatments for apple scab in orchards. A 2 per cent solution is effective in sterilizing tools and in disinfecting tree wounds (Table 36).

THE DITHIOCARBAMIC ACID DERIVATIVES. These consist of a number of non-corrosive and relatively non-poisonous compounds that are effective against a wide range of fungous diseases, especially some previously difficult to control. They are mainly protectants but do not appear to have as long a residual effect as the coppers, and under epiphytotic conditions must be applied more frequently (every 3 to 5 days for late blight of potatoes or tomatoes). They are available as wettable powders, as dusts (10-15 per cent active ingredient), and one formulation, Dithane D-14, as a water-miscible liquid. Zinc, iron, and sodium salts of dithiocarbamic acid compose the majority of the formulations. The salts are compatible with many other spray ingredients; but the iron salts are incompatible with copper, bentonite, and lime; and the zinc salts are not safe on roses.

THE PHENYL-MERCURY COMPOUNDS. These are characterized by the commercial compound Puratized Agricultural Spray, which is a water-soluble liquid with eradicant as well as with protectant value.

The Puratized formulations contain mercury, are poisonous, and may burn or irritate the skin in concentrated form, but the diluted sprays are not irritating to the skin. They are used mainly for turf diseases, some ornamental tree diseases, and apple or pear scab during or after rains up through the calyx or petal fall stage. They give better control of scab on apple foliage than on the fruit. Beyond the calyx stage poisonous residues may result: there is no tolerance for mercury on fruit. The spray is much safer on foliage than lime-sulfur but is not compatible with oils or with lime.

THE QUINONE DERIVATIVES. These are characterized by the commercial products called Phygon and Spergon, which are light-brown or yellow wettable powders for use as foliage sprays or for some seed treatments. Phygon acts primarily as a protectant but is reported to be an eradicant for apple scab as well. It has been reported to give from good to poor results in the various fruit areas. It is relatively safe to handle and is compatible with DDT, rotenone, lead arsenate, chlordane, and lime but is non-compatible with summer oils. Spergon is used chiefly in seed treatments.

THE QUINOLINOLATE DERIVATIVES. These are new organic copper or zinc compounds in wettable powder form that have shown considerable promise as protectants for some fruit and vegetable diseases. Their high cost has curtailed their use considerably.

THE GLYOXALIDINE DERIVATIVES. These promising materials are available under the name of Crag Fruit Fungicides: 341B or 341C. The 341B form is a wettable powder and the 341C form is a water-miscible solution. They are reported to be protectants with excellent tenacity, to be safe to handle with usual precautions, and to produce no residue problem. There are also indications that the 341C form when used in the full spray schedule for apple scab control may inhibit red mite build-up. Fruits are not injured by the recommended spray dosages, but tomatoes, potatoes, and melons have shown injurious effects. The glyoxolidines are compatible with DDT, nicotine sulfate, summer oils, lead arsenate, and hydrated lime but not with benzene hexachloride.

ORTHOCIDE 406 WETTABLE (n-trichloromethylthio tetrahydrophthalimide). This fungicide appears to have many desirable characteristics: it may be used safely on a large number of crops; it is effective against a wide range of diseases on fruits and vegetables; it is an effective seed protectant; it has a low order of toxicity to warm-blooded animals; and it should create no spray-residue problem. Orthocide 406 acts as a protectant against many diseases, but for apple scab it also stops or inhibits infections and thus prevents its spread.

CHEMOTHERAPY

The approach to plant disease control through internal chemical immunization and chemical cure (chemotherapy) is a relatively new and promising field. A few notable successes have been achieved, but considerably more experimental work must be done to determine the future possibilities of this method of disease control. In some cases the chemicals that have curative value may also have some immunization effects, depending on the length of time they remain in active form within the plant. This approach to plant disease control has found some success so far in the treatment of plants affected with vascular diseases causing wilts and with virus diseases. Thus for the first time chemical control of some of these diseases not affected by seed treatment or by fungicide applications may be possible.

To date, chemotherapy has been used most successfully in the control of non-infectious nutritional disturbances due to deficiencies of nutrient elements such as iron, zinc, copper, and boron. These deficiencies can be cured or prevented by supplying the plants with the necessary nutrients through root feedings, foliage sprays, or trunk injections. Chlorosis due to iron deficiency may be cured by supplying soluble iron salts. Zinc deficiency disease of some citrus and nut trees can be cured in a similar manner. Boron deficiency troubles commonly found in fruits and vegetables on sandy soils may be overcome by the addition of small amounts of borax to the

TABLE 36

NEW ORGANICS USED IN PLANT TREATMENTS

Chemical	Common and Trade Names	Principal Uses
	Dithiocarbamic Acid Derivatives	
Tetramethylthiuram disulfide	Thiram,* Tersan	Brown patch of turf
Ferric dimethyldithiocarbamate	Ferbam,* Fermate, Karbam (Black), Ferradow	Anthracnose diseases, rust diseases, apple scab, black spot of rose, etc.
Zinc dimethyl dithiocarbamate	Ziram,* Zerlate, Zincate, Karbam (White), Zimate	Bitter rot, apple rusts, cherry and celery blights, anthracnose, brown rot, early blight of potato and tomato, cucurbit diseases (alternated with coppers on tomatoes and cucurbits)
Disodium ethylene bis-dithiocarbamate (usually used with zinc sulfate and lime)	Nabam,* Dithane D-14, Thiodow	Tomato and celery blights, late blight of potato, etc.
Zinc ethylene bis-dithiocarbamate	Zineb,* Parzate, Dithane Z-78	Celery and carrot blights, late blight of potato and tomato, etc.

Table 36 (Continued)

Chemical	Common and Trade Names	Principal Uses
	Phenyl-Mercury Compounds	
Phenylmercuri triethanol ammonium lactate	Puratized Agricultural Spray	Apple scab (use only during or after rains), anthracnose of beans, cucurbits, and ornamental trees
Phenylmercuric acetate	Tag	Apple scab (use only during or after rains)
	Quinone Derivatives	
2,3-dichloro-1,4-naphthaquinone	Phygon-XL	Apple scab, brown rot, cherry leaf spot
Tetrachloroparabenzoquinone	Spergon	Seed treatments
	Dinitro Compounds	
Sodium dinitro-*o*-cresylate	Elgetol, Dinitro-sol, Krenite	Eradicant-dormant or delayed-dormant sprays for apple scab, peach leaf curl, spur blight of raspberries, black rot of grape, etc.

Table 36 (continued)

Chemical	Common and Trade Names	Principal Uses
Dinitro-*o*-cyclohexylphenol	Dinitro, DN Dry	Eradicant-dormant or delayed-dormant sprays for apple scab, peach leaf curl, spur blight of raspberries, black rot of grape, etc.
Triethanolamine salt of dinitro-*o*-sec-butyl phenol	DN 289, Elgetol 318	Strictly dormant spray for insect and disease control on fruits and ornamentals
	Quinolinolate Derivatives	
Copper 8-quinolinolate	Bioquin 1	Promising for many diseases—still experimental
Zinc 8-quinolinolate	Bioquin 100	Promising for many diseases—still experimental
	Glyoxalidines	
2-heptadecyl, 2-pentadecyl, and 2-heptadecenyl glyoxalidines	Crag Apple Fungicide (341C)	Apple scab

Table 36 (Continued)

Chemical	Common and Trade Names	Principal Uses
2-heptadecyl, 2-pentadecyl, and 2-heptadecenyl glyoxalidines	Crag Cherry Fungicide (341B)	Cherry leaf spot, black spot of rose
	Others	
n-trichloromethylthio tetrahydrophthalimide	Orthocide 406	Promising for many fruit, vegetable, and ornamental diseases

*Common names coined by the American Phytopathological Society.

soil. Special fertilizers containing borax or magnesium may be obtained in boron-deficient or magnesium-deficient areas.

Chemotherapy in the form of selective fungicidal action so as to kill or inactivate the disease-causing organism without severe harm to the plant has been found successful in some cases. It has been found possible to inactivate the virus of X-disease of peach by chemotherapy. This is the first time that a cure for a virus disease has been accomplished by this means. Injection of p-aminobenzene sulfonamide (0.05 per cent concentration) into healthy seedling peach trees on which diseased buds had been grafted gave 100 per cent control (Horsfall, Stoddard, and Dimond, "Chemical Therapy for Plant Diseases," Agr. Chemicals 2:3, 1947). Under field conditions calcium chloride watered into the soil gave the best results with 20 to 30 per cent fewer new infections over untreated trees and a significant improvement in the condition of previously infected trees.

Mr. E. M. Stoddard of the Connecticut Agricultural Experiment Station has obtained 100 per cent control of the red stele fungous disease of strawberries with a subsurface application of Dithane D-14 (nabam) at a concentration of 1 1/2 per cent. Surface and foliage applications are harmful to the plants.

Another new chemotherapy is to supply antidotes for toxins and toxic by-products that do the actual harm instead of attacking the disease-causing organisms themselves. This treatment shows some promise in vascular diseases (wilts), some root rots, and other pathological conditions. The toxin produced in the bleeding canker of hardwoods may be counteracted by injecting diamino azobenzene dihydrochloride (Orange Helione) into affected trees. The Dutch elm disease, which has also been found to be toxin-induced, may be antidoted with varying degrees of success with 8-hydroxy-quinoline benzoate. Young trees react much better to the treatment than old trees in which translocation difficulties are a chief factor.

QUESTIONS FOR DISCUSSION

1. Why do growers usually turn to fungicides first in connection with putting a stop to a threatening disease?

2. Chemical disease control is sometimes likened to a man proceding to mop up a wet floor without first stopping the water leak causing it. Explain.

3. Is there any hope that we may eventually get along without the use of fungicides?

4. Why is Bordeaux mixture still a very useful fungicide?

5. Why is a copper sulfate-lime dust effective only when applied to wet foliage?

6. What advantages do the "low-soluble" coppers have over Bordeaux mixture?

7. Liquid lime-sulfur, although a very effective fungicide for some diseases, has lost much of its popularity. Why?

8. Why do the more finely ground wettable sulfurs give better disease control than the coarser ones?

9. What makes some of the newer organic fungicides so outstanding?

10. Weekly applications of Dithane-zinc-lime sprays gave better control of early blight of celery than low-soluble copper sprays; but when applications lapsed for a month the copper-sprayed blocks looked much better. What does this show?

11. Do you think chemical immunization is a promising method of plant disease control?

12. Why is chemotherapy less successful in plants than in animals for disease control?

13. Why do young trees react much better than old trees to chemotherapy?

14. Why are insecticide-fungicide combinations useful?

15. Is the information given on fungicide packages similar to that given on insecticide packages?

16. How should one go about selecting the best fungicide to use for a certain disease?

17. How accurate is it to base control measures on the appearance of diseased plants?

18. In the chemical control of most leaf spots and blights a number of applications at intervals are necessary. Why?

19. Why is it impossible generally to control most wilt diseases after a plant is infected?

20. What are the different approaches to the prevention and control of rust diseases? Smut diseases?

21. What are the limitations of spray schedules for insect and disease control?

Chapter 19

WEEDS

The production of most crops involves a battle with weeds as well as with insects and plant diseases. It has been estimated that the average cost of tillage on cultivated lands is 16 per cent of the value of the crop and that more than one-half of the cultivation is necessary because of the presence of weeds.

Weed control has always been a serious problem in horticultural production and has become more serious in recent years with the great spread of old weeds and the introduction and wide dissemination of new ones. Man has shown a great indifference towards weeds and has allowed them to develop, spread, and disseminate their seed at will, although the harm they do to desirable plants may be as great or greater, but less spectacular, than that caused by insects or disease.

World-wide attention has lately centered on the weed problem, because of new and efficient methods of weed control, with the result that a new and distinct field of science based on improving weed control is developing. The yields of many crops and the grazing value of many pastures have been doubled and trebled by the use of adequate weed-control methods. It is very important that every landowner and grower consider weeds as a serious menace and become acquainted with the growth, reproduction, and latest control methods of those common to his area.

WHAT IS A WEED

From the standpoint of man, weeds are the undesirable species of the plant world. They are uncultivated plants that interfere with the growth of cultivated or desirable plants; or they are plants that are unsightly, injurious, or troublesome. Like cultivated plants, they vary in size, form, and habits, and are found in many plant families. Many are closely related to cultivated plant species and harbor the same insects and plant diseases. They generally differ from their more aristocratic brethren in their remarkable adaptation to their environment, great reproductive ability, and persistence to the point of distraction. The majority of weeds are products of the survival of the fittest and are able to withstand adverse environmental conditions that would wipe out many of our crop plants, which have been babied to the point where they have lost the power to survive without constant care.

DAMAGE CAUSED BY WEEDS

Weeds are one of the most important obstacles to maximum and quality crop production. They interfere with agricultural operations, increase labor, add to costs, and reduce quality and yields. Many of our cultivated crops are poor competitors of weeds, especially under unfavorable growing conditions.

Weeds crowd out and shade desirable crops; they rob them of soil nutrients and moisture; they harbor numerous insects and plant diseases (Tables 37 and 38); they depreciate land values; and some poison or injure man and animals (Table 39). In addition, weeds may clog up irrigation ditches; some species such as wild garlic, wild onion, and yarrow may impart undesirable flavor to milk products; they may reduce the carrying capacity of grazing lands; and the presence of their seeds in commercial seed crops reduces the value and desirability of these seed crops.

In their proper place, weeds may be useful as soil binders to prevent erosion, as forage in rough pasture land, and to restore organic matter to soil on uncultivated land. See Table 40 for scientific names of weeds.

TABLE 37

SOME WEEDS THAT HARBOR CROP-PLANT INSECTS

Weed	Insect	Crop Host
Mustards	Cabbage root maggot	Cabbage, broccoli, etc.
Mustards	Spinach aphis	Spinach, eggplant, cabbage, etc.
Wild cucumber	Striped cucumber beetle	Cucurbits
Wild cucumber	Squash vine borer	Cucurbits

Table 37 (Continued)

Weed	Insect	Crop Host
Live-for-ever	Melon aphis	Cucurbits
Chickweed	Melon aphis	Cucurbits
Plantain	Melon aphis	Cucurbits
Mustards	Melon aphis	Cucurbits
Wild morning-glory	Melon aphis	Cucurbits
Wild carrot	Carrot rust fly	Carrot, parsnip, celery
Wild parsnip	Carrot rust fly	Carrot, parsnip, celery
Wild carrot	Tarnished plant bug	Celery, dahlia, chrysanthemums, etc.
Ragweeds	Tarnished plant bug	Celery, dahlia, chrysanthemums, etc.
Rough pigweed	Tarnished plant bug	Celery, dahlia, chrysanthemums, etc.
Plantains	Rosy apple aphid	Apple
Dock	Rhubarb curculio	Rhubarb
Ragweed	Onion thrips	Onion
Mustards	Onion thrips	Onion
Nightshade	Onion thrips	Onion
Pokeweed	Greenhouse red spider	Rose, dahlia, carnation, etc.
Nightshades	Greenhouse red spider	Rose, dahlia, carnation, etc.
Ragweed	Common stalk borer	Tomato, corn, dahlia, aster, lily, etc.
Burdocks	Common stalk borer	Tomato, corn, dahlia, aster, lily, etc.
Lambs-quarters	Common stalk borer	Tomato, corn, dahlia, aster, lily, etc.

Table 37 (continued)

Weed	Insect	Crop Host
Numerous large-stemmed herbaceous weeds	European corn borer	Corn, dahlia, gladiolus, etc.
American crab	Plum curculio	Apple, peach, plum, cherry

TABLE 38

SOME WEEDS THAT HARBOR CROP DISEASES

Weed	Disease	Crop Host
Mustards	Club root	Cabbage, cauliflower, etc.
Quack-grass	Stem rust	Wheat, oats, barley
Wild oats	Stem rust	Wheat, oats, barley
Quack-grass	Ergot	Rye, barley
Cinquefoils	Strawberry leaf spot	Strawberries
Horse nettle	Septoria blight	Tomato
Pigweeds	Spinach mildew	Spinach, Swiss chard
Wild carrot	Carrot blight (macrosporium)	Carrot
Nightshades	Verticillium wilt	Eggplant
Galinsoga	Yellows (virus)	Lettuce, salsify, aster
Black-eyed Susan	Yellows (virus)	Lettuce, salsify, aster
Purslane speedwell	Yellows (virus)	Lettuce, salsify, aster
Pokeweed	Cucumber mosaic	Cucumber
Ground-cherries	Cucumber mosaic	Cucumber
Milkweed	Cucumber mosaic	Cucumber
Catnip	Cucumber mosaic	Cucumber

Table 38 (Continued)

Weed	Disease	Crop Host
Motherwort	Cucumber mosaic	Cucumber
Ground-cherries	Tomato mosaic	Tomato
Nightshade	Tomato mosaic	Tomato
Nightshades	Potato mosaic	Potato
Choke-cherry	X-disease	Peach, sour cherry

TABLE 39

SOME WEEDS POISONOUS TO MAN AND ANIMALS

Buttercups
Choke-cherry (wilted leaves)
Cocklebur (seedlings)
Foxglove
Horsetails
Larkspur
Laurels
Meadow deathcamas
Nightshades
Poison hemlock
Poison ivy
Poison sumac
Pokeweed
Sneeze-weed
Spurges
Water hemlock

LIFE HISTORY AND CLASSIFICATION OF WEEDS

Weeds, like other plants, may be divided into five groups from the standpoint of length of life and characteristics: summer annuals, winter annuals, biennials, herbaceous perennials, and woody perennials.

SUMMER ANNUALS. These complete their life cycle in 1 year or less: the seed germinates in the spring, the plant grows during the summer and dies in the fall or earlier. The seed is the only link that continues the species. Figure 170 illustrates the typical life cycle of a summer annual when the soil is undisturbed after the initial tillage. Examples: Figs. 171 and 172.

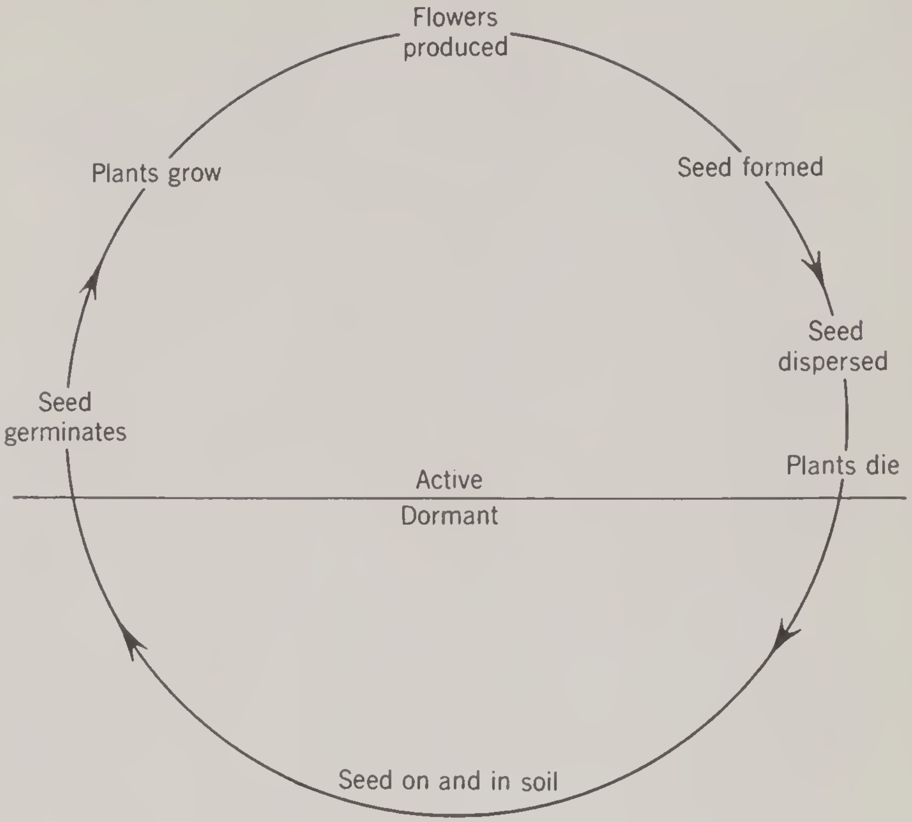


FIG. 170. The life history of a typical summer annual.

Cultivation has altered the usual seasonal life history of weeds and has made them much more prolific than would be possible under natural conditions. When the soil is disturbed at intervals in cultivation, weed seeds that have been buried and ordinarily would remain dormant are brought near the surface, within their germinating range. Thus new crops of certain weeds may appear with each cultivation until the cool weather of late fall prevents seed germination. The number of new crops of weeds per season is limited mainly by the number of cultivations made in a field.

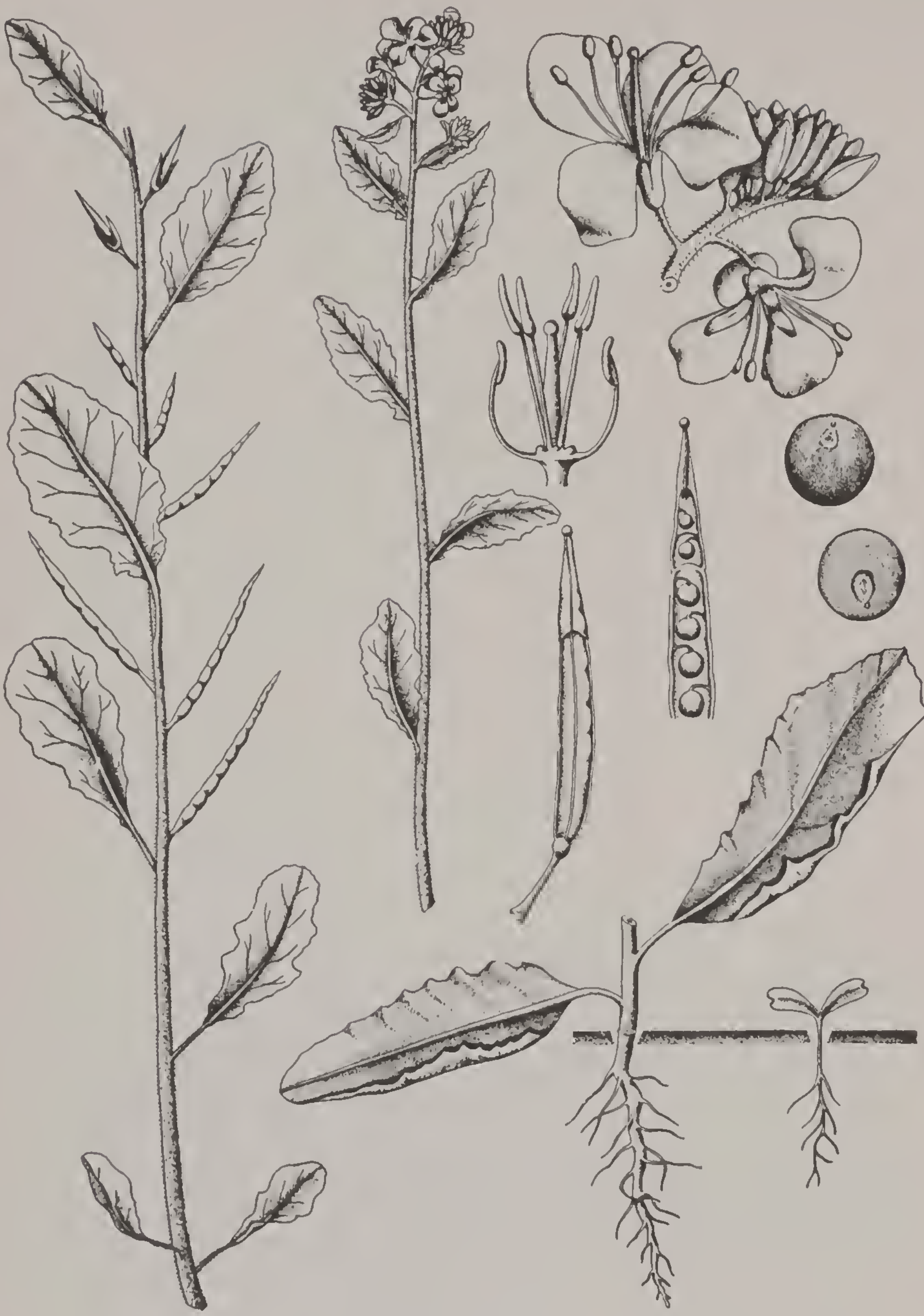


FIG. 171. Wild mustard (courtesy of Univ. of Minn.).

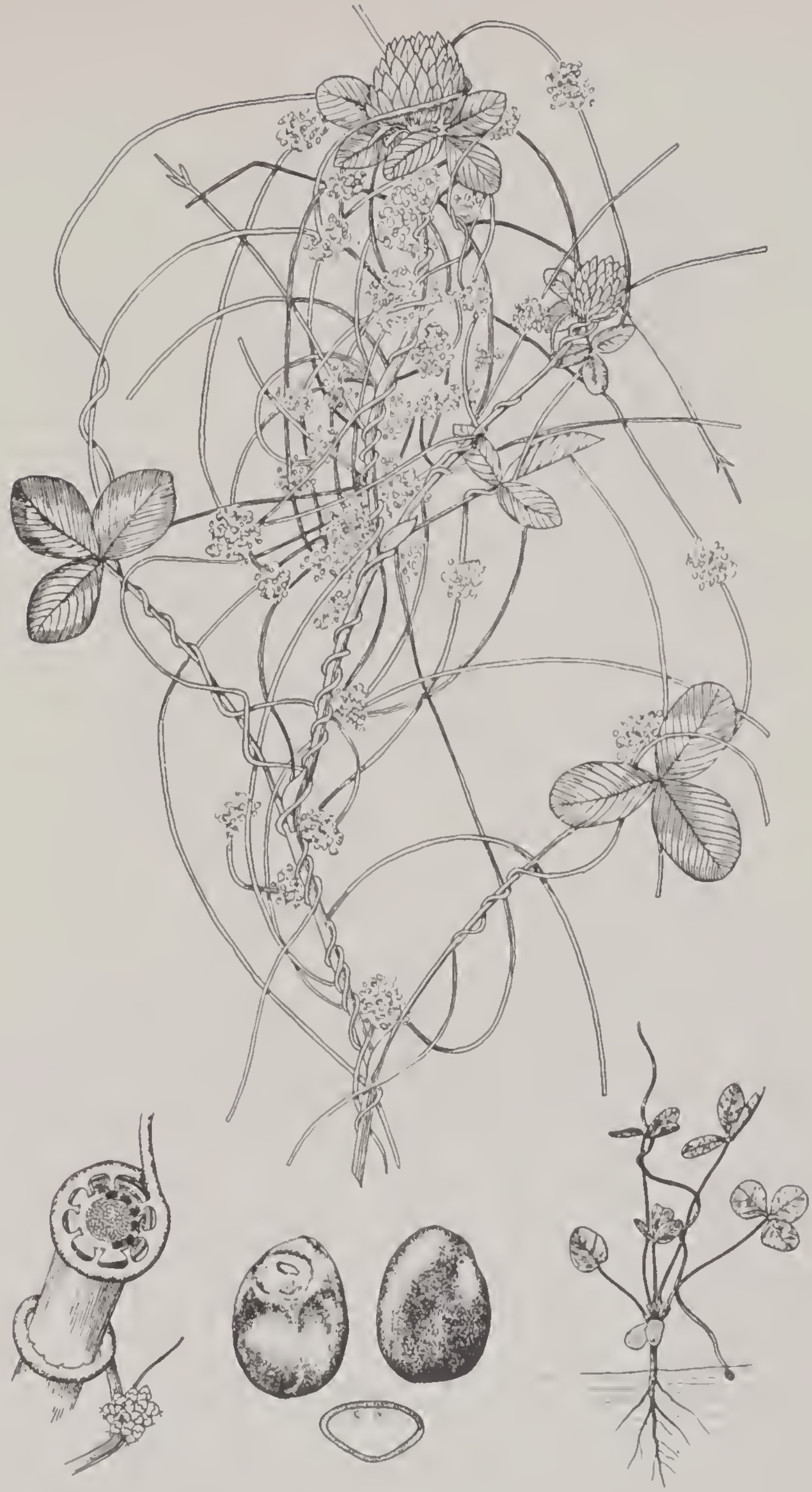


FIG. 172. Dodder (Purdue Univ., Ind. Ext. Bull. 246).

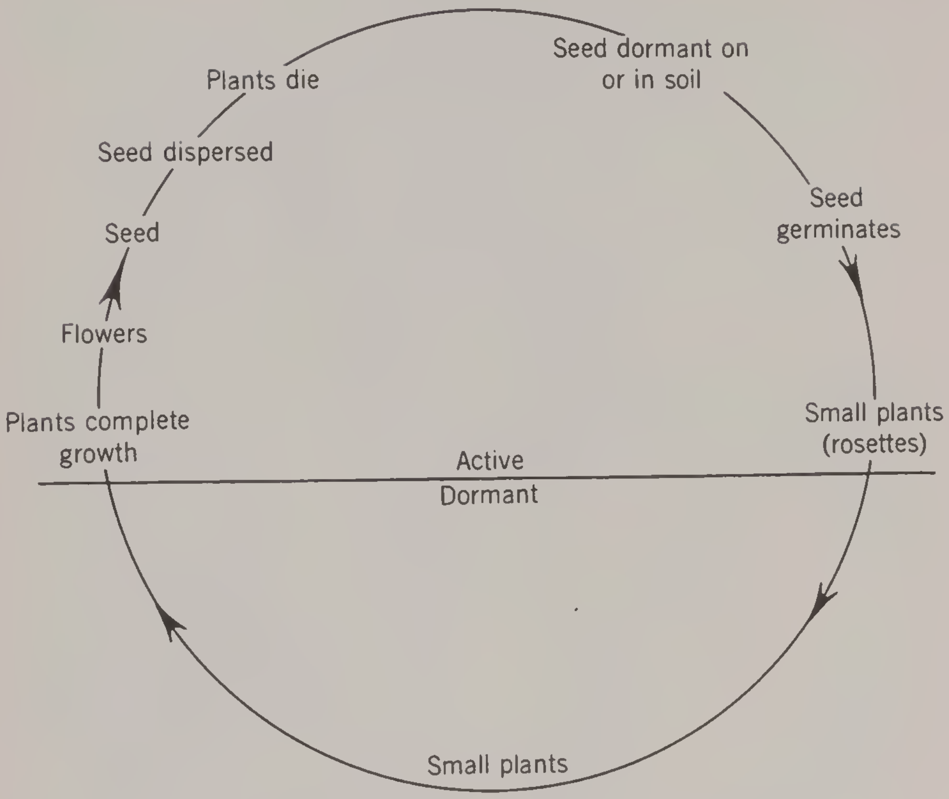


FIG. 173. Life history of a typical winter annual.

WINTER ANNUALS. These start from germinating seeds in the fall, overwinter as seedlings or small plants, blossom in the spring, and produce seed and die about midsummer (Fig. 173). Examples: Figs. 174 and 175.

All methods of controlling annuals are based on the prevention of seeding. Annuals in the early growth stages are most easily and cheaply destroyed, because their roots have no power of regeneration once the tops are killed. Both annuals and winter annuals should be destroyed before or during flowering. Many annuals such as mustards and purslane flower over a period of several weeks and thus have all stages of seed development from flower to mature seed on them; they should be destroyed in the early blooming stage or before.

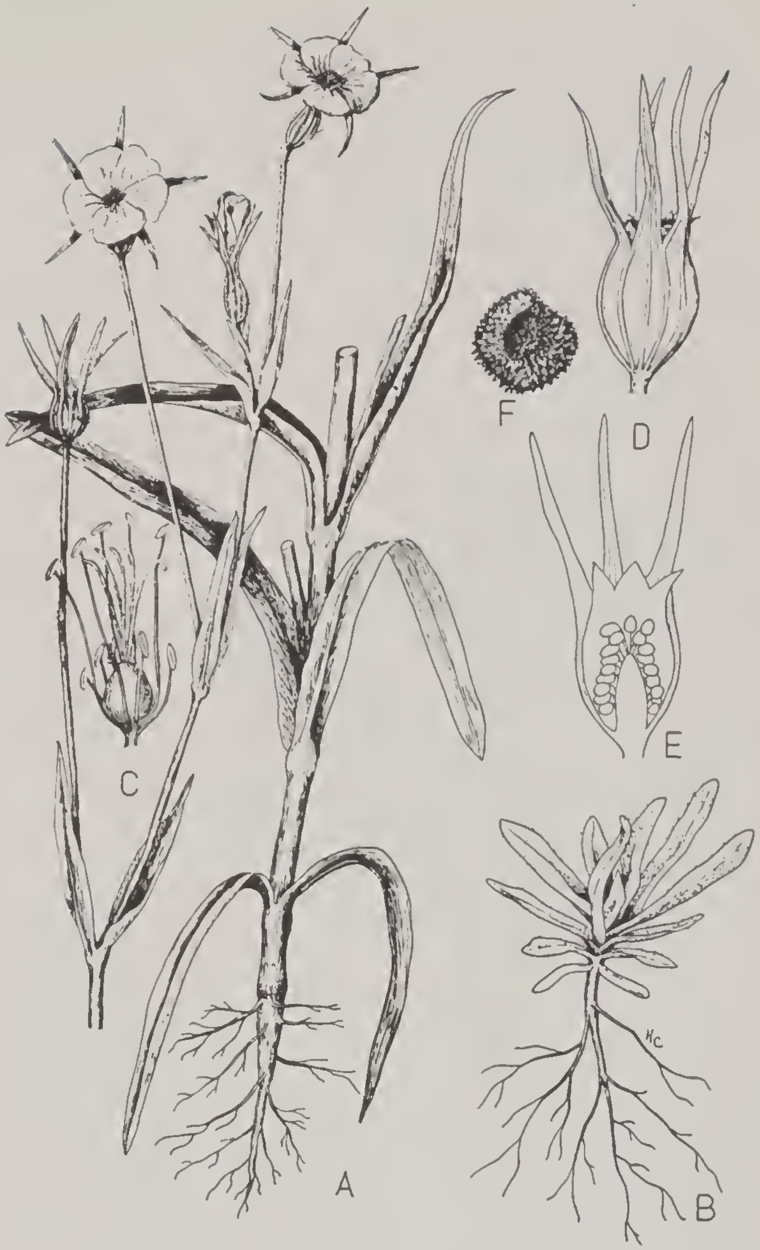


FIG. 174. Corn cockle. Note B, rosette stage (Cornell Ext. Bull. 538).

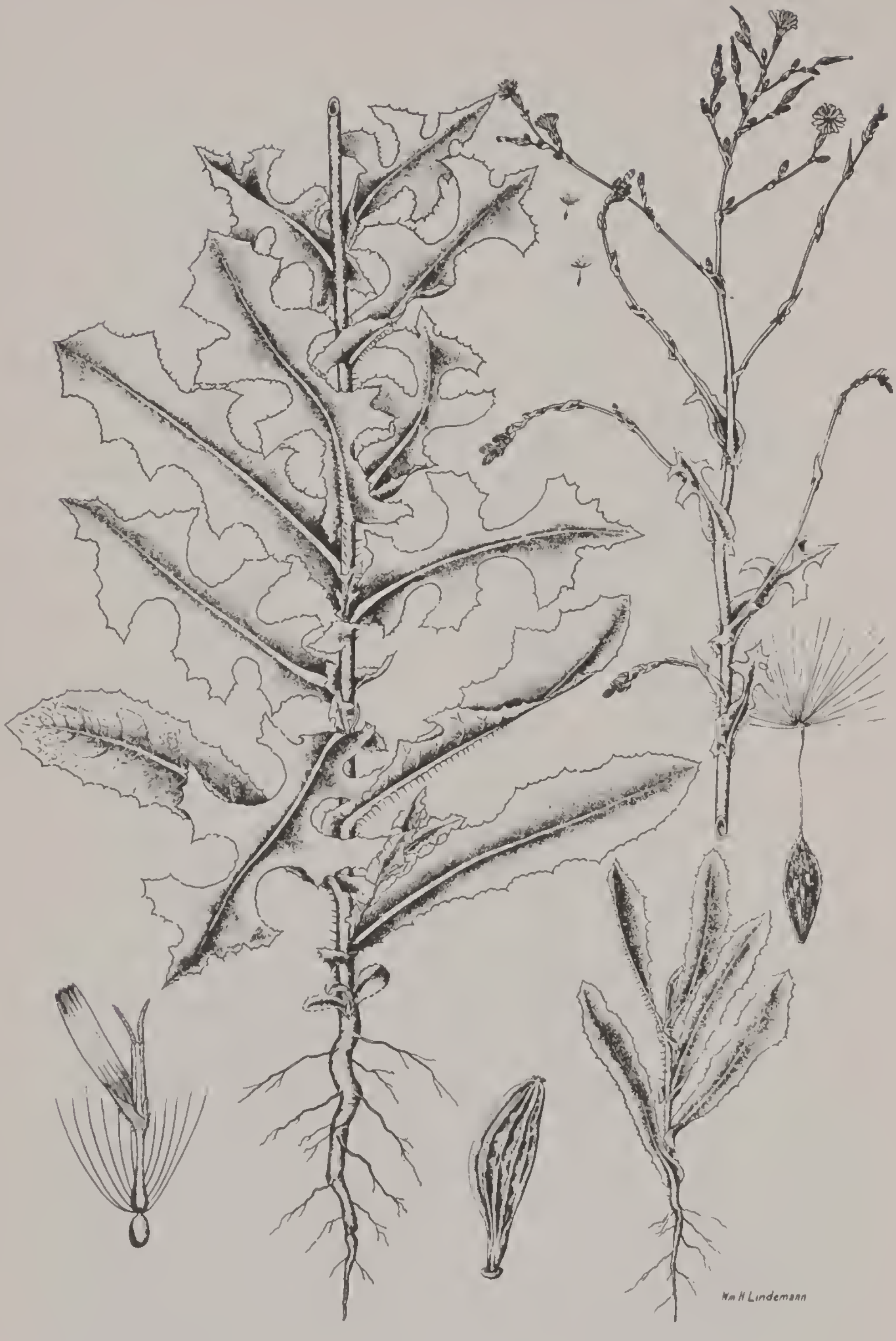


FIG. 175. Wild lettuce (Minn. Agr. Expt. Sta. Bull. 381).

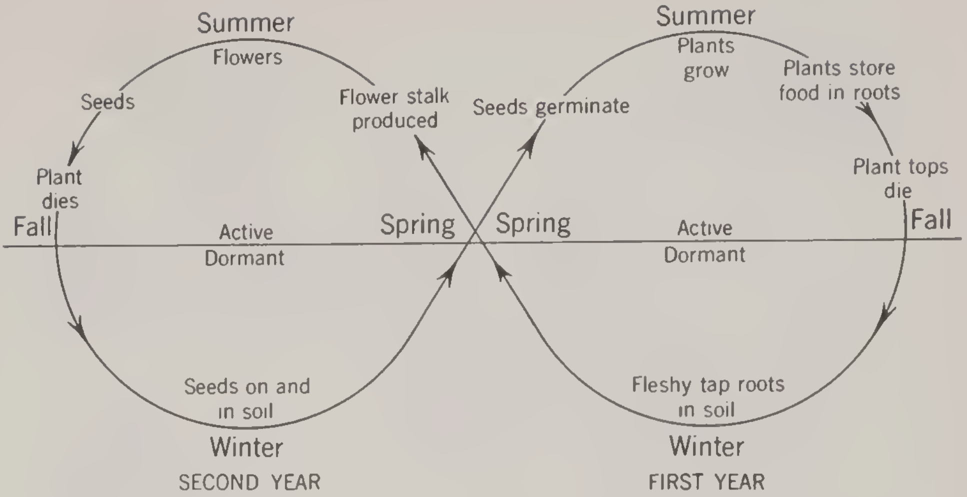


FIG. 176. The life history of a typical biennial weed.

BIENNIALS. Biennials take 2 years to complete their life cycle. In the first year the plants start from germinating seeds in the spring, grow, and store food; in the second year a flower stalk is produced from the roots, seeds are produced, and the plant dies (Fig. 176).

Biennial plants are frequently of a rosette form and have fleshy roots or other organs for food storage (Figs. 177 and 178). They are generally restricted to uncultivated areas, since tillage tends to be detrimental to them. Seedstalks are at times sent up very rapidly early in the season; therefore control methods should be centered on the young weeds or rosettes before this happens.

PERENNIALS. Perennials live for 3 or more years. They may be divided into herbaceous perennials and woody perennials. Herbaceous perennials may be classified on the basis of vegetative reproduction into simple perennials (Fig. 179), bulbous perennials (Fig. 180), and creeping perennials (Fig. 181). Herbaceous perennials may not produce seed in the first year, but do produce seed annually thereafter as long as the plants live. Woody perennials may not produce seed for the first several years, but once the weed plant matures it produces seed annually. The aerial parts of herbaceous perennials usually die back in the winter, but the plants regenerate themselves from rootstocks, rhizomes, bulbs, or bublets in the ground (Fig. 182).

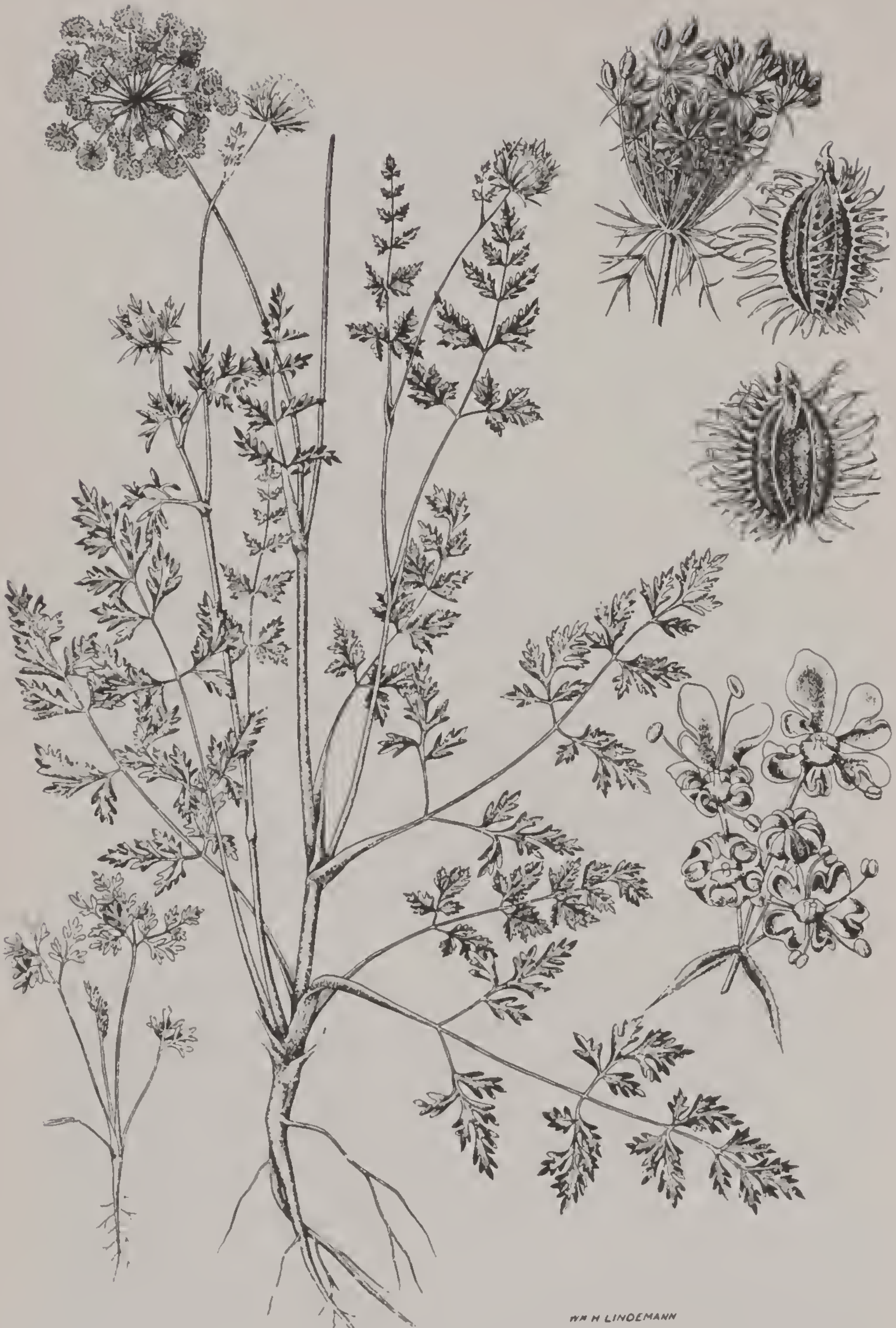


FIG. 177. Wild carrot (Minn. Agr. Ext. Service Ext. Bull. 183).

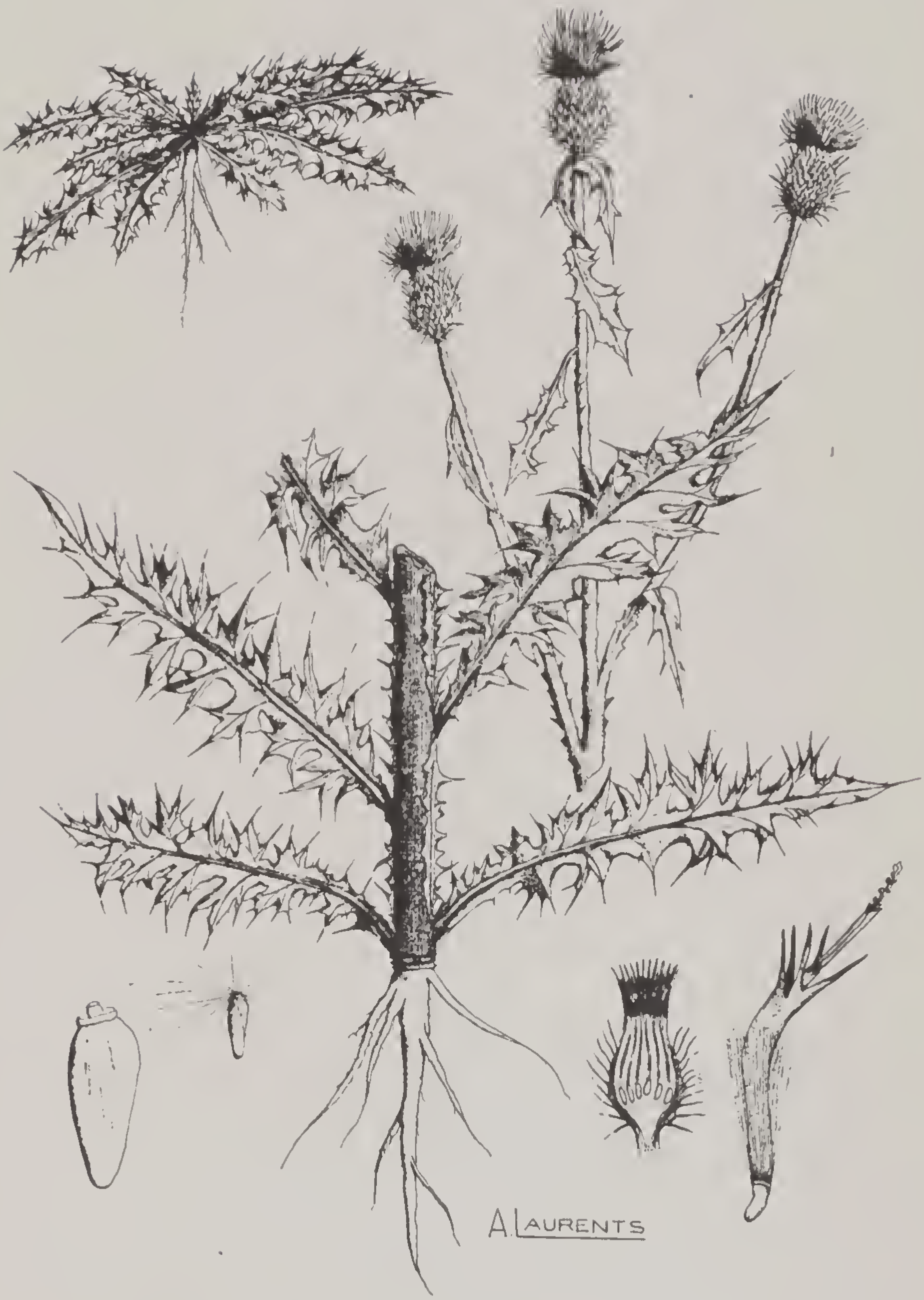


FIG. 178. Bull thistle (*Minn. Agr. Expt. Sta. Bull.* 381).

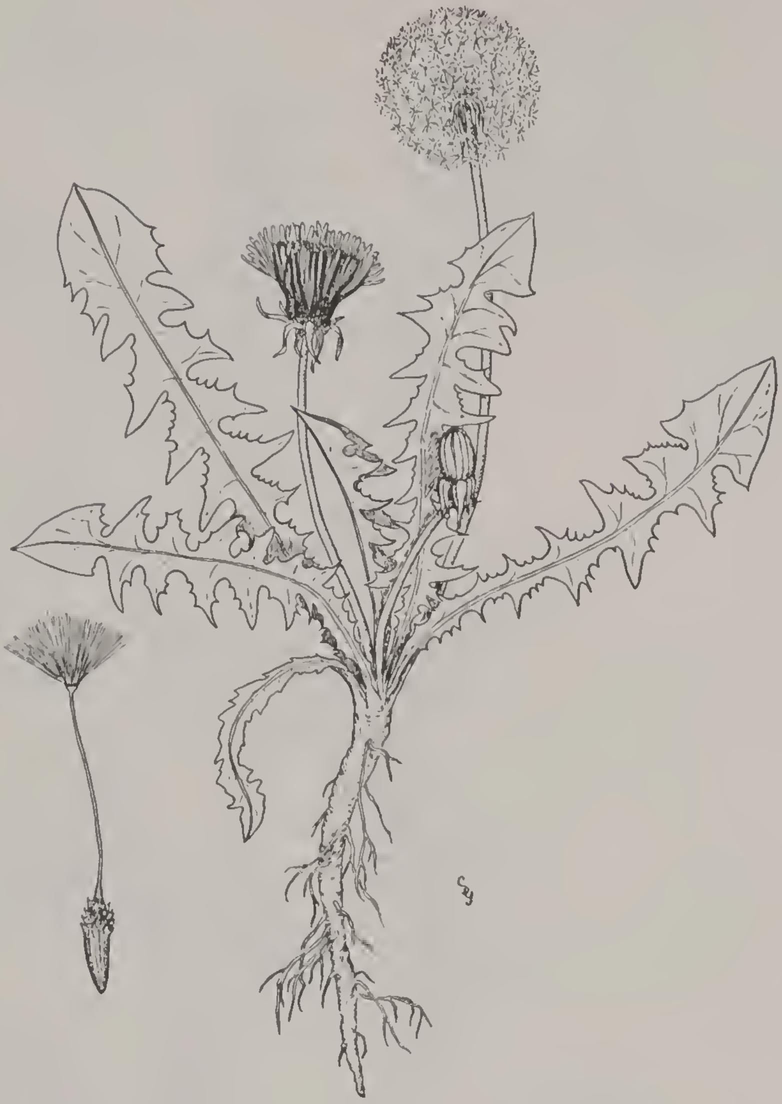


FIG. 179. Common dandelion (Jenkins and Jackman, *Ore. State Coll. Ext. Bull.* 544).

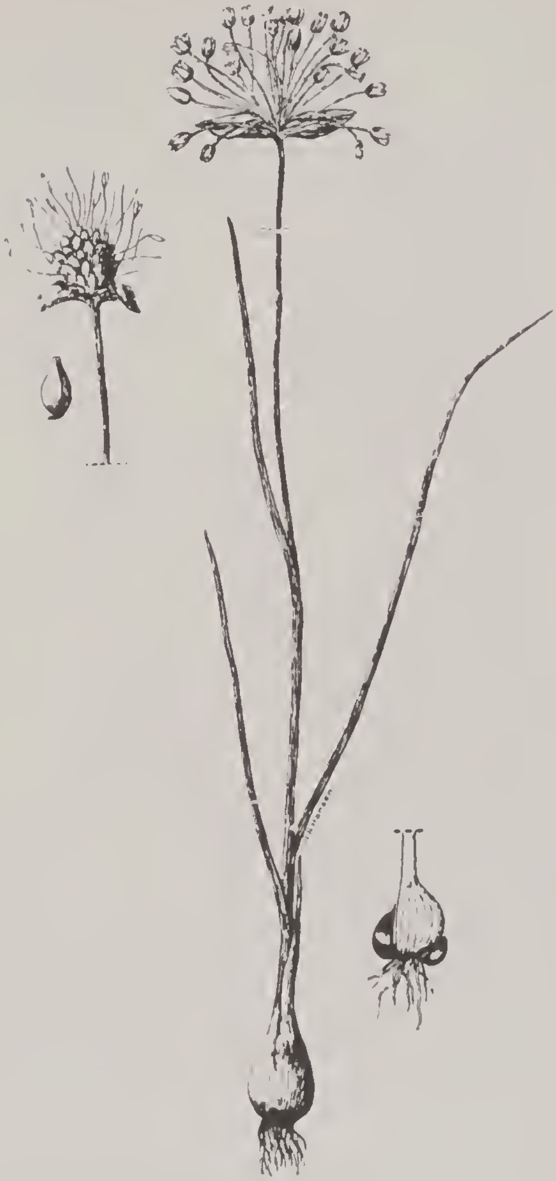


FIG. 180. Wild garlic, Note bulblets on bulb (Purdue Univ., Ind. Ext. Bull. 246).

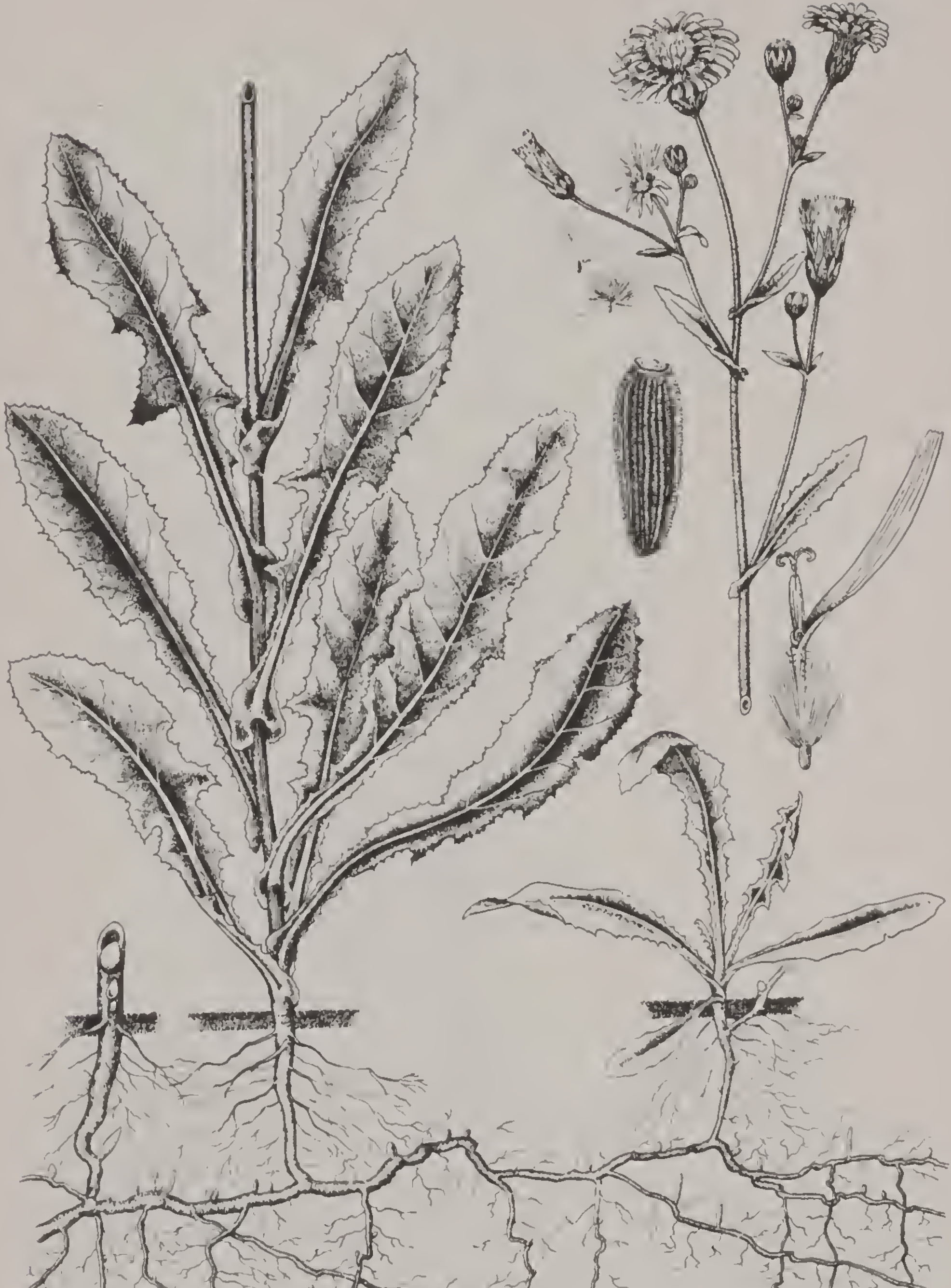


FIG. 181. Sow thistle. (Minn. Agr. Ext. Service Bull. 183).

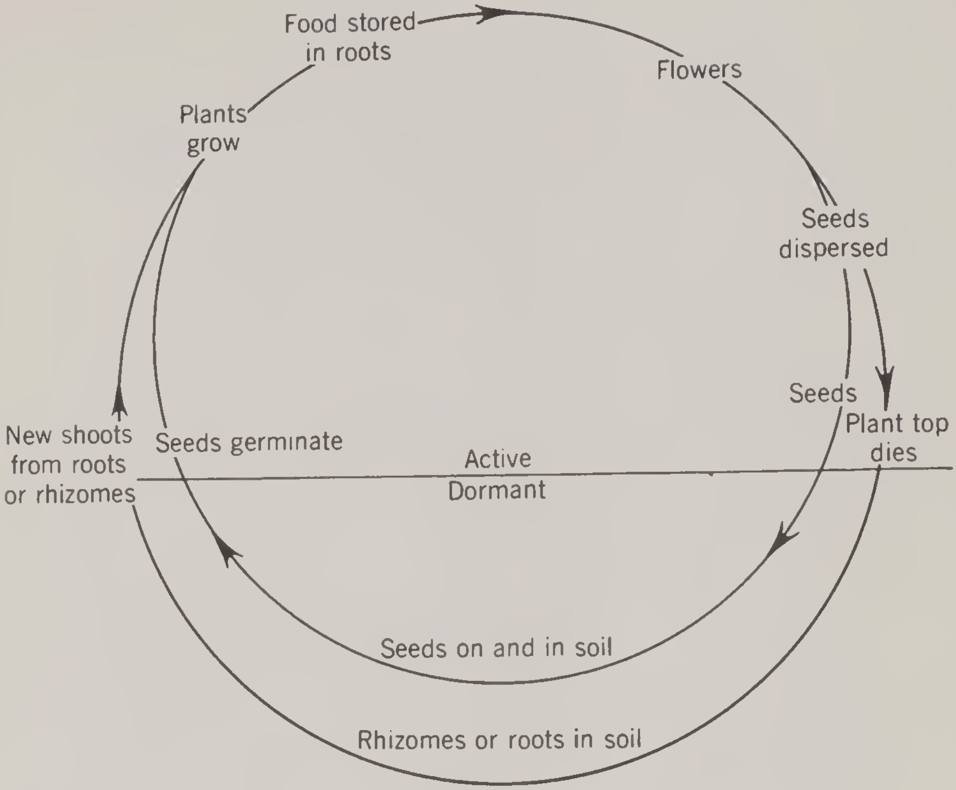


FIG. 182. Life history of a typical herbaceous perennial.

Simple perennials under natural conditions reproduce by seed. Vegetative reproduction occurs only when roots or crown are cut during cultivation. Each cut piece may then produce a new plant. Examples: dandelion, curly dock, common plantain, and buckhorn plantain.

Bulbous perennials reproduce by bulbs and bulblets (Fig. 180) as well as by seed. Wild garlic, for example, can reproduce itself from seed, aerial bulblets, and secondary bulbs at the base of the old bulb. Nut-grass reproduces itself from seed and from the tiny tubers produced at the ends of rhizomes (Fig. 183).

Creeping perennials spread by seed or by stolons along the ground surface, by rhizomes beneath the soil, by tiny tubers, or by creeping rootstocks. Mouse-ear chickweed, knotweed, St. Johns-wort, and the hawkweeds spread by sto-

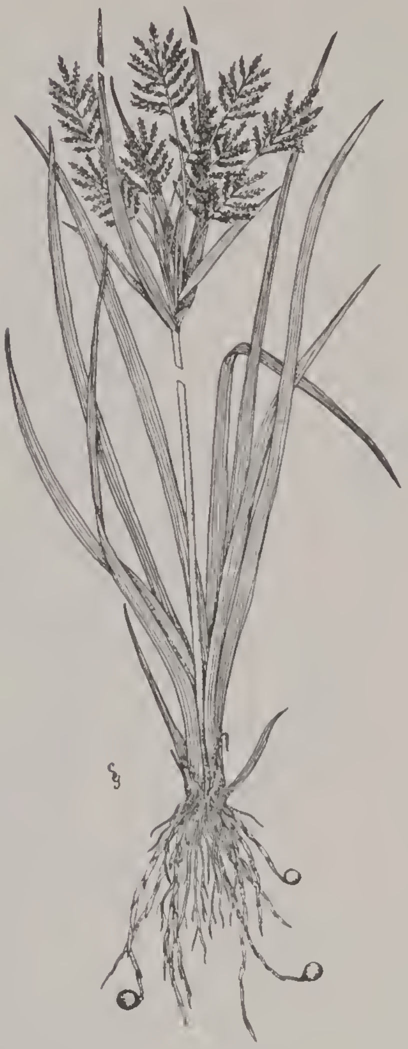

E. R. Jackman

FIG. 183. Yellow nut-grass showing underground "nuts" (Jenkins and Jackman, *Ore. State Coll. Ext. Bull.* 568).

lons (Fig. 184), quack-grass, hedge bindweed, and Johnson-grass spread by rhizomes (Fig. 185); nut-grass spreads by small, hard tubers (Fig. 183); perennial sow thistle, sheep sorrel, western ragweed, and poison ivy spread by creeping rootstocks (Fig. 186); and wild morning-glory and Canada thistle may produce new shoots from both roots and rhizomes (Figs. 187 and 188). Creeping perennials may rapidly spread

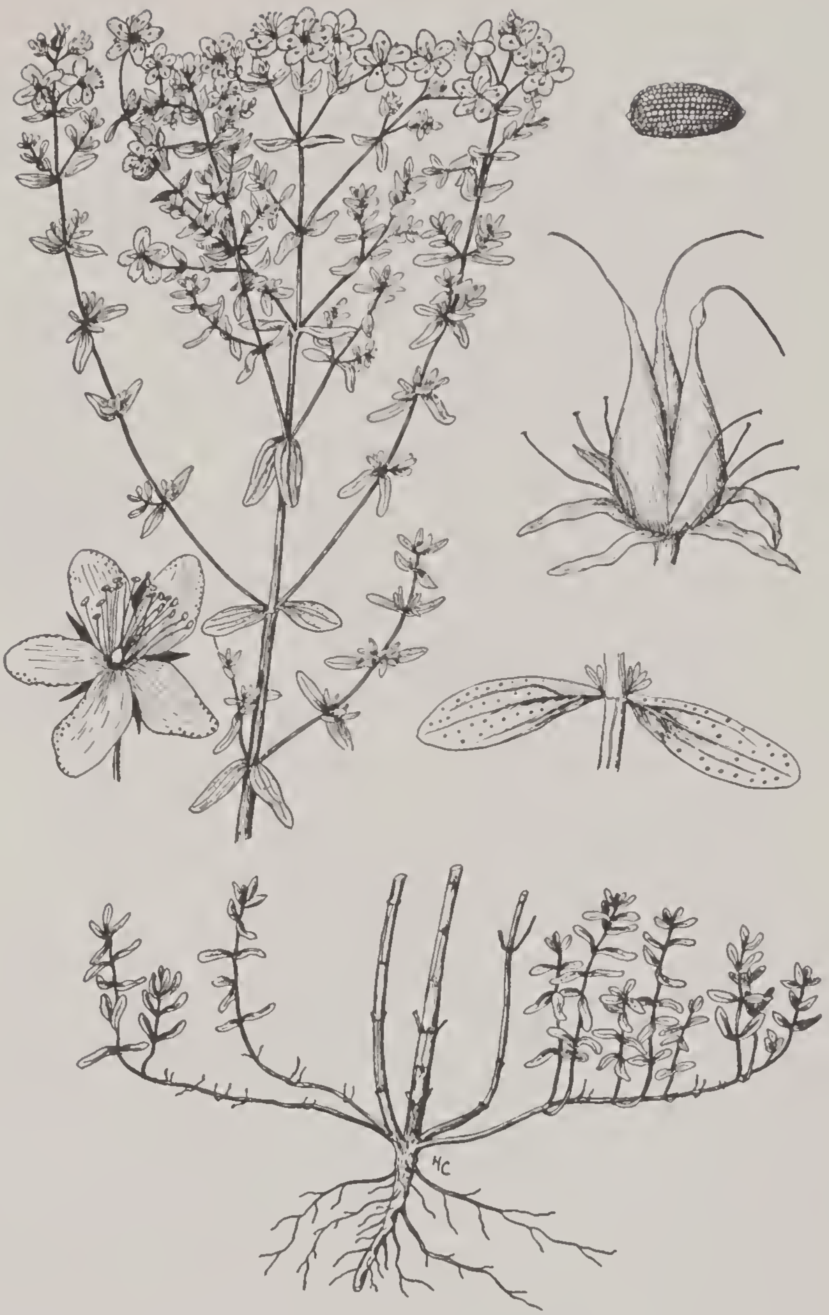


FIG. 184. St. Johns-wort (*Cornell Ext. Bull.* 538).

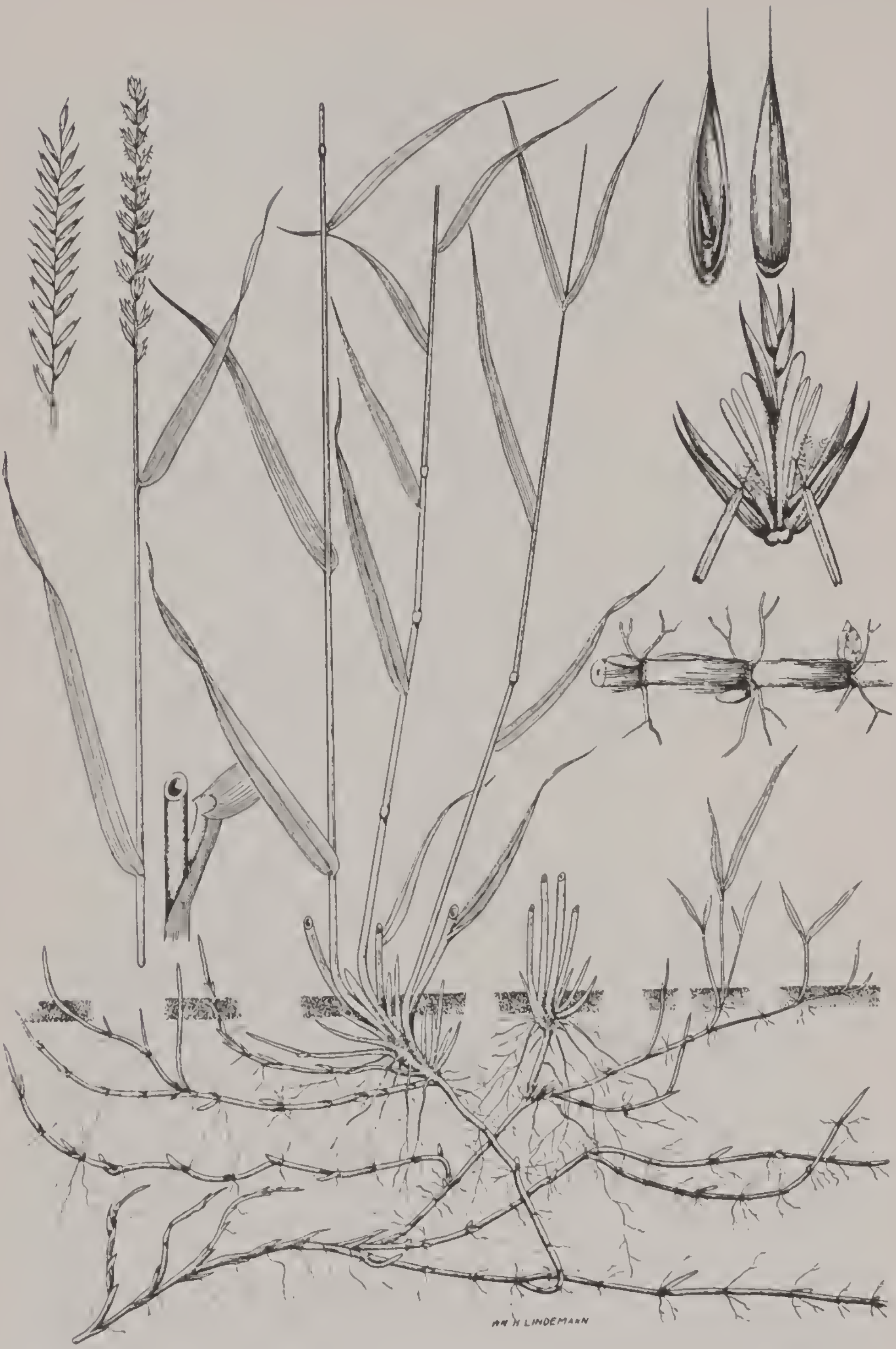


FIG. 185. Quack-grass (Minn. Agr. Ext. Service Ext. Bull. 183).

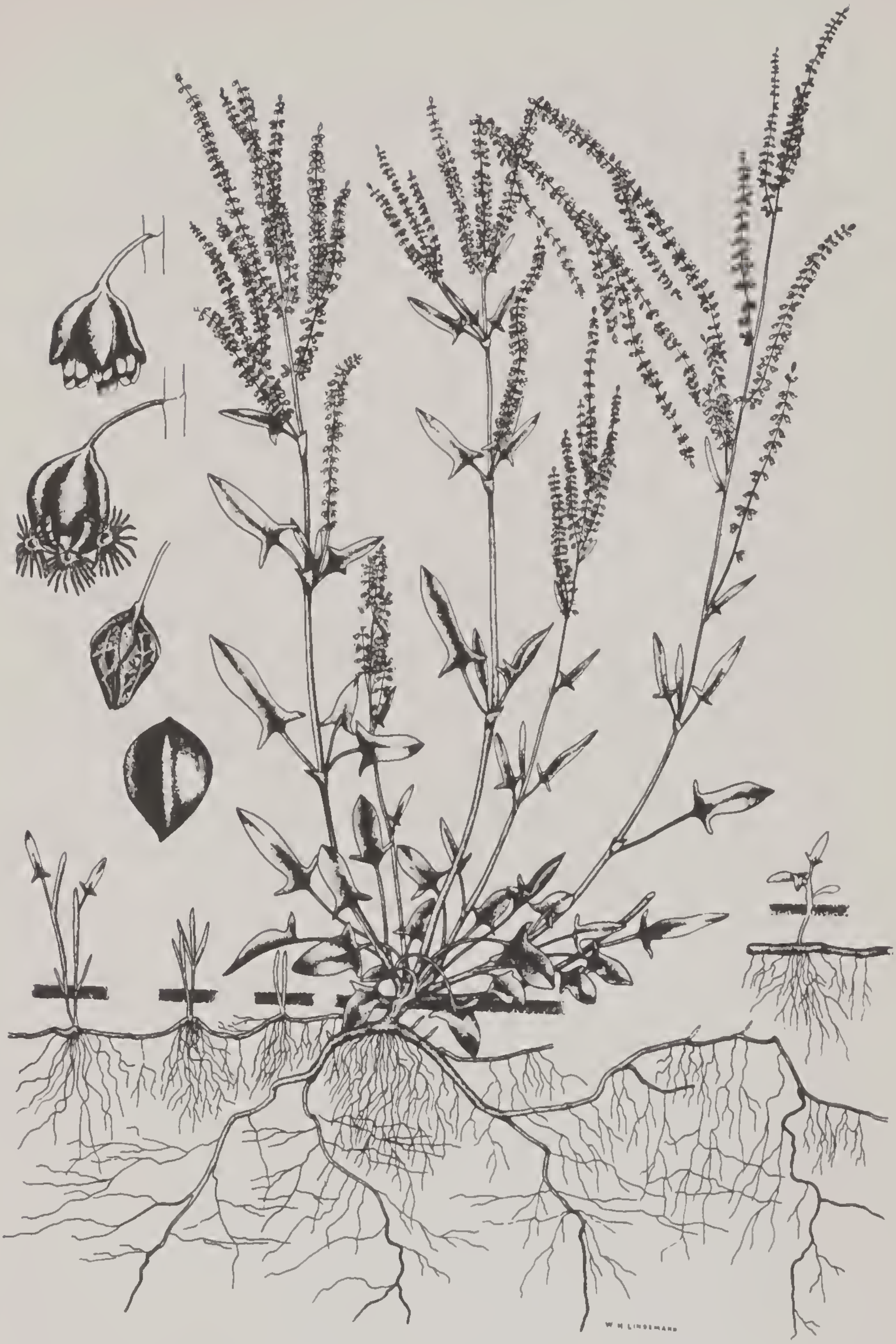


FIG. 186. Sheep sorrel (*Minn. Agr. Ext. Service Ext. Bull.* 183).

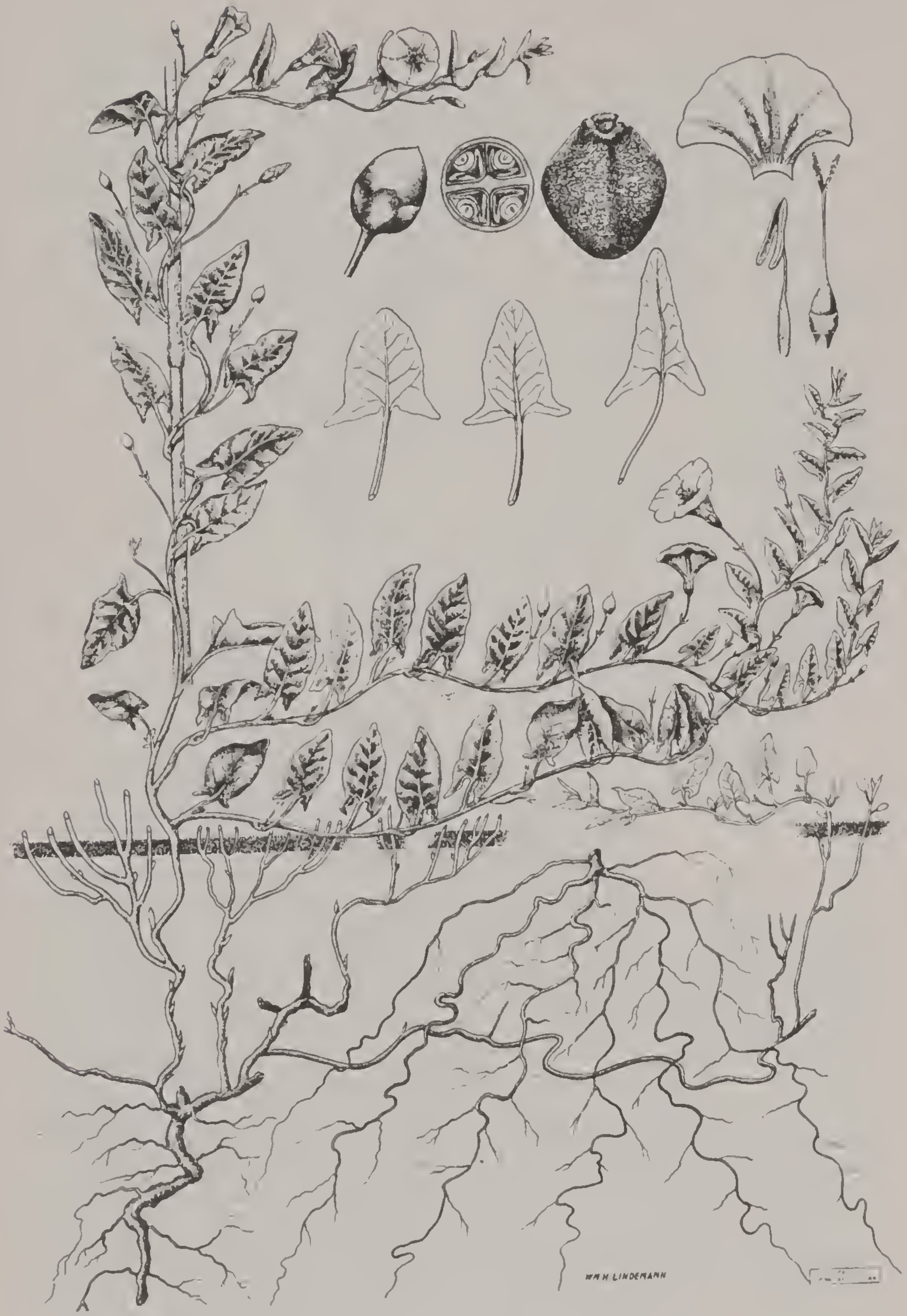


FIG. 187. Wild morning-glory (Minn. Agr. Ext. Service Ext. Bull. 183).

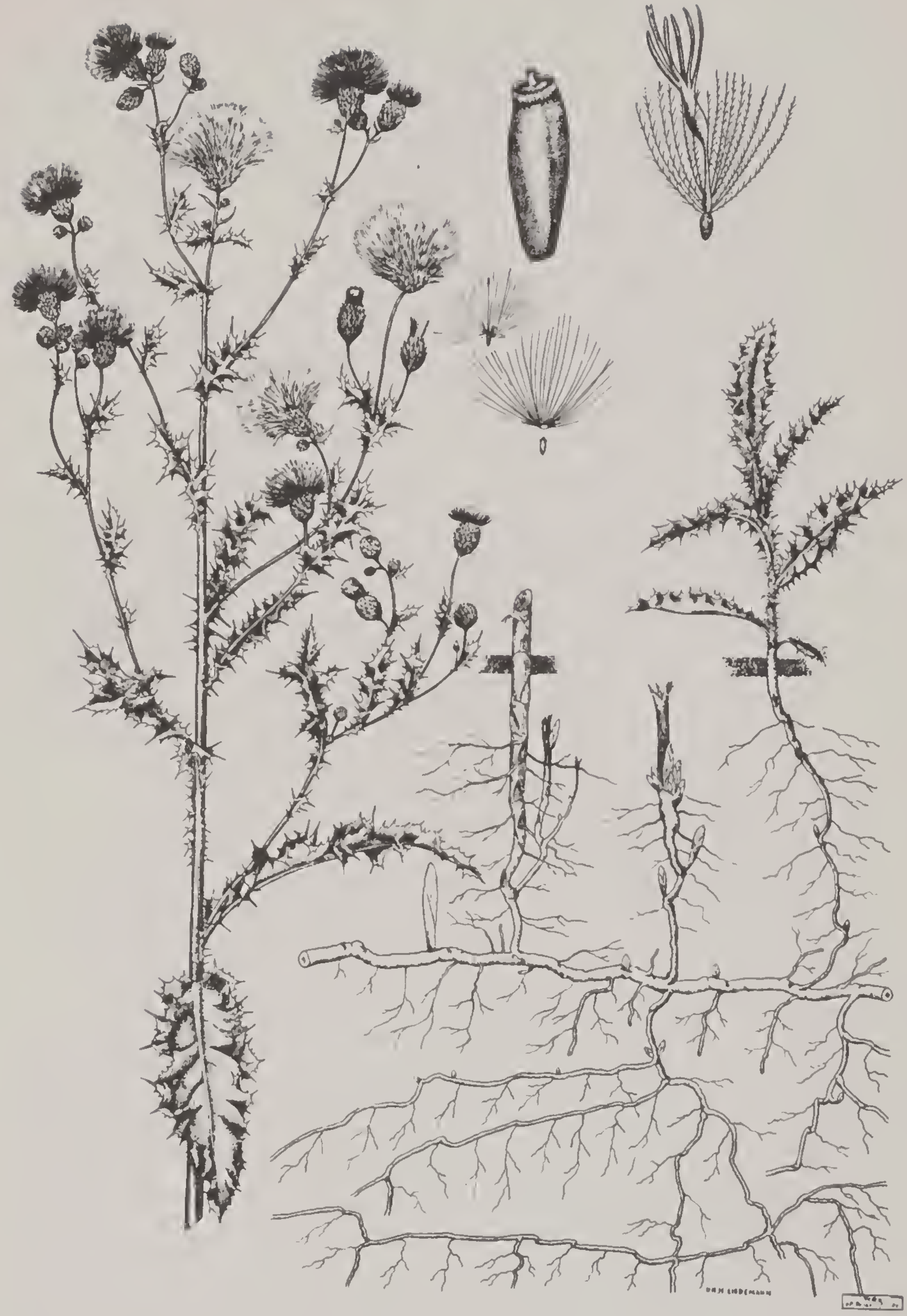


FIG. 188. Canada thistle (*Minn. Agr. Ext. Service Ext. Bull.* 183).

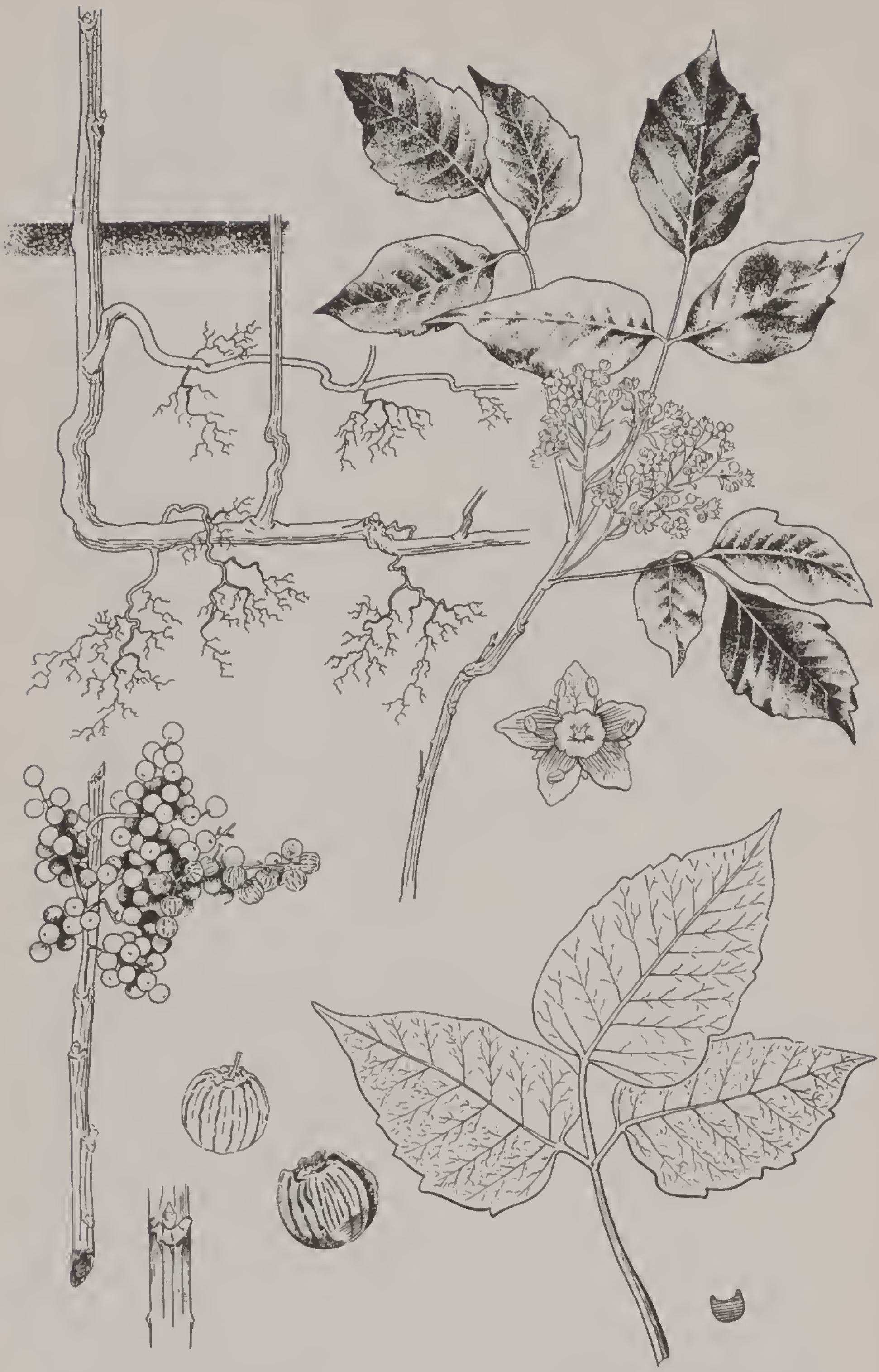


FIG. 189. Poison ivy (Minn. Agr. Expt. Sta. Bull. 381).

laterally from a single plant. Perennial sow thistle in 1 season may produce rhizomes over an area 5 feet in diameter. Canada thistle may produce a solid patch 60 feet in diameter in 3 years.

Woody perennials are generally in the form of shrubs, bushes, vines, trees, or briers (Fig. 189). They may not produce seed for the first few years or more; but once the plants mature seeds are usually produced annually. Some woody perennials such as poison ivy, wild blackberry, and wild raspberry have the creeping habit and reproduce vegetatively from rootstocks. A few such as dewberries propagate from stolons. Woody perennials usually do not die back during the winter, and the whole plant continues to increase in size annually. Otherwise their annual life history is similar to that shown in Fig. 182.

To combat perennial weeds, the established old plants must be eradicated, and seeds and seedlings already in the soil must be killed. Most weeds such as Bermuda grass, quackgrass, and sheep sorrel are shallow-rooted, creeping perennials with reproductive parts 6 to 10 inches in the soil where they can be reached by cultivation or plowing, but wild morning-glory and Canada thistle are deep-rooted and can propagate from depths below ordinary plowing.

The life history of weeds may vary somewhat with climate. In some situations annuals may be either summer or winter annuals; biennials may grow as perennials or annuals; and annuals may grow as perennials. Table 40 lists all the weeds mentioned in this and following chapters, with classifications and scientific names.

ASSOCIATION OF WEEDS WITH SOILS

The prevalence of weeds is often due to agricultural practices and not to the fertility of a soil. Most weeds are adapted to different soil conditions and cannot be definitely associated with any soil type. Under certain conditions, however, the abundance of some weeds may frequently be associated with soil type and reaction. Investigations have shown that the majority of weeds show a gradually decreasing or increasing frequency from acid to neutral soil reaction. The actual presence of certain weeds, however, is no indication of soil reaction; but their prevalence may give some indication of it.

As an example, sheep sorrel grows most abundantly on an acid soil because of the absence of competition from plants that are more sensitive to acid soil. Lime reduces sheep sorrel because it produces soil conditions that favor growth of other plants that help exclude sorrel. Abundance of lime in soil does not inhibit the presence and growth of sheep sorrel, but allows other plants to crowd it out.

WEED AND CROP ASSOCIATIONS

Different crops are infested with their characteristic weeds because their life cycle, habits, and characteristics are such as to allow them to compete successfully with the crops. Cultural operations and crop rotation may encourage or discourage specific weeds.

Small cereals are usually infested with weeds of the mustard family; rice and cranberries with water or damp-soil weeds; and vegetable gardens with purslane, pigweeds, shepherds-purse, lambs-quarters, crab-grass, and galinsoga. Quack-grass, perennial sow thistle, plantains, bull thistle, hawkweeds, sheep sorrel, docks, and goldenrods are common in meadows and in pasture lands; dandelion, yarrow, sheep sorrel, crab-grass, annual bluegrass, common chickweed, and plantains are common on lawns and turfs. The abandoned farm lands of the east are covered with weeds such as quack-grass, tall field buttercup, St. Johns-wort, wild carrot, butter-and-eggs, ox-eye daisy, chicory, Canada thistle, hawkweeds, and black-eyed Susan. Hay fields commonly have weeds such as ragweed, fleabane, wild carrot, quack-grass, ox-eye daisy, Canada thistle, orange hawkweed, yellow paintbrush, sheep sorrel, curly dock, and tall field buttercup.

TABLE 40

REFERENCE LIST OF SCIENTIFIC NAMES OF WEEDS MENTIONED IN THE TEXT

Key: A–Annual, WA–Winter Annual, B–Biennial, P–Herbaceous Perennial; WP–Woody Perennial

Common Name	Classification	Scientific Name
American crab	WP	Pyrus coronaria
Annual bluegrass	A	Poa annua
Barberry	WP	Berberis vulgaris
Barnyard-grass	A	Echinochloa crus-galli
Bear mat	P	Chamaebatia foliolosa
Beggar-ticks	A	Bidens frondosa
Bermuda grass	P or A	Cynodon dactylon
Black mustard	A or WA	Brassica nigra
Black nightshade	A	Solanum nigrum
Black-eyed Susan	B	Rudbeckia hirta
Bracted plantain	A or WA	Plantago aristata
Brambles	WP	Rubus spp.
Bristly foxtail	A	Setaria verticillata
Broad-leaved plantain	P	Plantago major
Buckhorn plantain	P	Plantago lanceolata
Buffalo bur	A	Solanum rostratum
Bull thistle	B	Cirsium lanceolatum
Burdocks	B	Arctium spp.
Butter-and-eggs	P	Linaria vulgaris
Buttercups	B or P	Ranunculus spp.
Camel's thorn	WP	Alhagi camelorum
Canada fleabane	A	Erigeron canadensis
Canada thistle	P	Cirsium arvense
Catnip	P	Nepeta cataria
Cat-tails	P	Typha spp.
Chess (downy brome-grass)	A or WA	Bromus tectorum
Chickweed	A or WA	Stellaria spp.
Chicory	P	Cichorium intybus
Chokeberry	WP	Aronia melanocarpa
Choke-cherry	WP	Prunus virginiana
Cinquefoil, rough	A or B	Potentilla norvegica hirsuta

Table 40 (continued)

Common Name	Classification	Scientific Name
Cinquefoils (five-fingers)	P	*Potentilla* spp.
Climbing milkweed	P	*Gonolobus laevis*
Cocklebur	A	*Xanthium orientale*
Common chickweed	A or WA	*Stellaria media*
Corn cockle	WA	*Agrostemma githago*
Cottonwoods	WP	*Populus* spp.
Crab-grass	A	*Digitaria* spp.
Curly dock	P	*Rumex crispus*
Dandelion	P	*Taraxacum officinale*
Devils shoestring	P	*Lygodesmia juncea*
Dewberries	WP	*Rubus flagellaris*
Docks	P	*Rumex* spp.
Dodders	A	*Cuscuta* spp.
Downy brome-grass (chess)	A or WA	*Bromus tectorum*
Evening primrose	B	*Oenothera biennis*
Fan-weed (penny cress)	A or WA	*Thlaspi arvense*
Field bindweed (wild morning-glory)	P	*Convolvulus arvensis*
Field poppy	A	*Papaver rhoeas*
Five-fingers (cinquefoils)	P	*Potentilla* spp.
Fleabane	A	*Erigeron* spp.
Foxglove	B	*Digitalis purpurea*
Foxtails	A	*Setaria* spp.
Galinsoga	A	*Galinsoga parviflora*
Giant ragweed	A	*Ambrosia trifida*
Goldenrod	P	*Solidago serotina*
Gorse	WP	*Ulex europoeus*
Green foxtail	A	*Setaria viridis*
Ground-cherries	P	*Physalis* spp.
Hairy crab-grass	A	*Digitaria sanguinalis*
Hawkweeds	P	*Hieracium* spp.
Hazels	WP	*Corylus* spp.

Table 40 (continued)

Common Name	Classification	Scientific Name
Hedge bindweed	P	*Convolvulus sepium*
Hoary cress	P	*Lepidium draba*
Horse nettle	P	*Solanum carolinense*
Horsetails	P	*Equisetum* spp.
Hounds-tongue	B	*Cynoglossum officinale*
Jimson-weed	A	*Datura stramonium*
Johnson-grass	P	*Holcus halepensis*
Klamath-weed (St. Johns-wort)	P	*Hypericum perforatum*
Knotweed	A	*Polygonum aviculare*
Lambs-quarters	A	*Chenopodium album*
Larkspur	P	*Delphinium simplex*
Laurels	WP	*Kalmia* spp.
Lawn pennywort	P	*Hydrocotyle rotundifolia*
Leafy spurge	P	*Euphorbia escula*
Live-for-ever	P	*Sedum triphyllum*
Loosestrife	P	*Lysimachia terrestris*
Marsh cress	A, B, or P	*Roripa palustris*
Meadow death-camas	P	*Zygadenus venenosus*
Mesquite	WP	*Prosopis juliflora glandulosa*
Milkweed	P	*Asclepias syriaca*
Moth mullein	B	*Verbascum blattaria*
Motherwort	P	*Leonurus cardiaca*
Mouse-ear chickweed	A	*Cerastium viscosum*
Mullein	B	*Verbascum thapsus*
Mustards	A, B, or WA	*Brassica* spp.
Nightshades	A or P	*Solanum* spp.
Nimblewill	P	*Muhlenbergia schreberi*
Nut-grasses	P	*Cyperus* spp.
Oaks	WP	*Quercus* spp.
Orange hawkweed	P	*Hieracium aurantiacum*
Osage orange	P	*Maclura pomifera*

Table 40 (continued)

Common Name	Classification	Scientific Name
Ox-eye daisy	P	Chrysanthemum leucanthemum pinnatifidum
Penny cress (fanweed)	A or WA	Thlaspi arvense
Pepper-grass	A or B	Lepidium virginicum
Perennial sow thistle	P	Sonchus arvensis
Pigweeds	A	Chenopodium spp.
Plantains	P	Plantago spp.
Poison ivy	WP	Rhus toxicodendron
Poison sumac	WP	Toxicodendron vernix
Poison hemlock	B	Conium maculatum
Pokeweed	P	Phytolacca americana
Prickly pear cactuses	P	Opuntia spp.
Purslane	A	Portulaca oleracea
Purslane speedwell	A or WA	Veronica peregrina
Quack-grass	P	Agropyron repens
Ragweed	A	Ambrosia artemisiifolia
Ragweed, western	P	Ambrosia psilostachya
Ragwort	A or WA	Senecio vulgaris
Rough daisy fleabane	A or B	Erigeron ramosus
Rough pigweed	A	Amaranthus hybridus
Russian knapweed	P	Centaurea repens
Russian thistle	A	Salsola kali tenuifolia
Sage-brush	WP	Artemisia tridentata
St. Johns-wort (Klamath-weed)	P	Hypericum perforatum
Sandbur	A	Cenchrus pauciflorus
Scrub oak	WP	Quercus ilicifolia
Sedges	P	Cyperus spp.
Sheep sorrel	P	Rumex acetosella
Shepherds-purse	A or WA	Capsella bursa-pastoris
Smartweed	A	Polygonum spp.
Sneeze-weed	P	Helenium autumnale

Table 40 (continued)

Common Name	Classification	Scientific Name
Sour dock	P	Rumex acetosa
Spurges	A or P	Euphorbia spp.
Stinging nettle	P	Urtica dioica
Sunflower	A	Helianthus annuus
Sweet clover	A or B	Melilotus spp.
Tall field buttercup	P	Ranunculus acris
Tumble weed	A	Amaranthus graecizans
Water hemlock	P	Cicuta maculata
Water hyacinth	P	Eichhornia crassipes
Water smartweed	A	Polygonum hydropiper
White violets	P	Viola spp.
Wild bean	P	Apios tuberosa
Wild blackberries	WP	Rubus spp.
Wild carrot	B	Daucus carota
Wild cherries	WP	Prunus spp.
Wild cucumber	A	Echinocystis lobata
Wild garlic	P	Allium vineale
Wild lettuce	A or WA	Lactuca scariola integrata
Wild morning-glory (field bindweed)	P	Convolvulus arvensis
Wild mustard	A	Brassica arvensis
Wild oats	A	Avena fatua
Wild parsnip	B	Pastinaca sativa
Wild radish	A or WA	Raphanus raphanistrum
Wild raspberries	WP	Rubus spp.
Winter cress	WA or B	Barbarea vulgaris
Wood sorrels	P	Oxalis spp.
Yarrow	P	Achillea millefolium
Yellow foxtail	A	Setaria lutescens
Yellow nut-grass	P	Cyperus esculentus
Yellow paintbrush	P	Hieracium pratense
Yellow sweet clover	A or B	Melilotus officinalis
Yellow star-thistle	A	Centaurea solstitialis

QUESTIONS FOR DISCUSSION

1. Do our current agricultural practices encourage or discourage weeds? Explain your answer.
2. Could a cultivated plant become a weed? Could a weed become a cultivated plant?
3. Why don't growers usually get as excited about the presence of weeds as they do about the presence of insects or diseases, although injury to the crop may be as great or greater?
4. What do you suppose has held back the development of the science of weeds and weed control?
5. Why are efficient methods of weed control important?
6. What is your own definition of a weed?
7. What factors make weeds so persistent?
8. In what ways do weeds harm cultivated crops? Animals and man?
9. Why may weeds be referred to as tough plants?
10. What effects do weeds have on insect pests and on diseases of cultivated crops?
11. Differentiate between summer annuals, winter annuals, biennials, herbaceous perennials, and woody perennials.
12. In the case of annuals, what is the only means by which the species can be continued?
13. When is the best time to destroy annuals? Perennials?
14. Why is tillage detrimental to biennials?
15. Why are creeping perennials so difficult to control?
16. Does the classification of weeds as annuals, biennials, and perennials hold under different environmental conditions?
17. What types of weeds are usually found in vegetable gardens? Lawns? Pastures? Meadows? Grain fields? Wasteland?
18. Does soil type have any effect on the absence or presence of certain weeds? Explain.

Chapter 20

THE REPRODUCTION OF WEEDS

Weeds are similar to other plants in their reproductive habits. Nearly all of them reproduce themselves by means of seeds, and many can in addition reproduce themselves vegetatively by means such as stolons, tubers, or rhizomes.

SEED REPRODUCTION

The number of seeds produced by weeds is generally very large although the actual number varies with the species and with the environmental conditions. The enormous numbers of seeds produced by single weed plants (Table 41) explains in part the abundance and persistence of weeds.

Some weed plants like Canada thistle and sheep sorrel are dioecious; that is, there are male and female plants bearing either staminate or pistilate flowers. Thus a patch of Canada thistle originating from one plant is unable to reproduce itself through seeds unless plants of the opposite sex are nearby and unless bees or other insects are present to do the pollinating. Most weeds, however, have either self-fertile flowers or insect-pollinated flowers. A few like the ragweeds are wind pollinated. The common dandelion is known to set seed without fertilization, although fertilization by bees usually occurs.

TABLE 41

APPROXIMATE ANNUAL SEED PRODUCTION BY SOME WEED PLANTS UNDER NORMAL CONDITIONS*

Plant	Seed Number
Green foxtail	34,000
Yellow foxtail	6,420
Quack-grass	11,400
Barnyard-grass	7,160
Stinging nettle	26,660
Sheep sorrel	250
Sour dock	29,500

Table 41 (Continued)

Plant	Seed Number
Lambs-quarters	72,450
Rough pigweed	117,400
Purslane	52,300
Black mustard	13,400
Penny cress	7,040
Shepherds-purse	38,500
Wild mustard	2,700
Leafy spurge	140
Buffalo bur	8,460
Mullein	223,200
Broad-leaved plantain	36,150
Burdock	31,600
Canada thistle	680
Giant ragweed	1,650
Perennial sow thistle	9,750

*From Sylvester and Porter, Iowa State Coll. Bull. P64.

LONGEVITY AND VIABILITY OF WEED SEEDS

Most weed seeds show many of the same characteristic reactions as the seeds of our common cultivated crops to environmental conditions, and in addition many show remarkable adaptiveness in maintaining the species from the standpoint of surviving unfavorable conditions and retaining their viability for a number of years.

Some weed seeds exhibit the characteristic of delayed germination; that is, they will not germinate immediately after they have ripened but will remain dormant for varying lengths of time until certain physiological changes, called afterripening, have taken place; for example, the wild oat whose seeds undergo little or no germination up to 5 months of age germinate up to 100 per cent at 18 months of age.

Other causes of inhibitions of germination may be due to environmental conditions such as low temperatures, lack of sufficient moisture, too low a light intensity, or burial in the soil below the germination range. The seeds of some plants have an impermeable or tough seed coat which may delay germination until environmental factors such as freezing and thawing or fungous and bacterial action gradually act on the coat to soften it or to make it more permeable to oxygen or to water.

Some plants such as purslane, galinsoga, and chickweed may mature viable seed when the plants are pulled up or cut at the flowering stage. Seeds in the milk-ripe stage of species such as curly dock, perennial sow thistle, dandelion, and many of the mustards will produce viable seeds when the plants are cut off. The immature seeds of field poppy and Jimson-weed germinate more readily than fully ripe seed. This may be because the seed coat is permeable to water in the immature seeds but becomes impermeable in mature seeds.

Longevity of Weed Seed in the Soil

It is important to know that the hard seeds of many weed species may retain their viability up to 50 years or more when they are buried below their germinating range in some soils. The seeds remain in a dormant condition and will not germinate unless brought up near the soil surface where temperature, oxygen supply, and possibly light intensity stimulate germination. This indicates the futility of weed control by plowing under weeds with ripened seeds, since they will outlive any crop rotation, and many of them will eventually be brought by cultivation to the surface where they may germinate. Every time the soil is plowed or cultivated a new batch of weed seed is brought up; if conditions are favorable, a new weed problem is created. It is better to keep weed seeds near the surface to encourage germination and subsequent destruction than to plow them under and be troubled for years to come. Table 42, recorded by the Michigan State Experiment Station, indicates the remarkable longevity of weed seeds buried in the soil. Additional data show that the seeds of three weed species, evening primrose, curly dock, and moth mullein, were found to retain some viability after 60 years of burial in the ground.

TABLE 42

VIABILITY OF WEED SEEDS IN THE SOIL*

Weed	No. Years Viability Retained
Black mustard	50 or more
Black nighshade	20 or more
Bristly foxtail	20 or more
Broad-leaved plantain	40 or more
Canada thistle	20 or more
Chickweed	30
Cinquefoil (five-finger)	20 or more
Dodder	20 or more
Horse nettle	11 or more
Lambs-quarters	40
Mullein	35
Penny cress	20 or more
Pepper-grass	40 or more
Purslane	50 or more
Quack-grass	4
Ragweed	40 or more
Rough pigweed	40 or more
Shepherds-purse	35
Smartweed	20 or more
Tumble weed	40
Yellow foxtail	30 or more
Yellow nut-grass	20 or more

*From Iowa State Coll. Bull. P64 (recorded by Mich. State Expt. Sta.).

Viability of Weed Seed Submerged in Water

Since water may be a factor in the dissemination of seed, and since flooding is often practiced for the control of other pests, it is of value to know how weed seeds react to submergence in water. Bermuda grass seed kept in flooded soil for 50 days showed 14 per cent germination, and Johnson-grass under the same conditions showed 23 per cent germination. Klamath-weed (St. Johns-wort) germinated better and faster after 20 days submergence in water; Russian knapweed showed 4 per cent germination after 61 days of submergence; burdocks showed 42 per cent germination after 153 days; and wild morning-glory seed were still firm after 209 days of submergence and germinated 96 per cent when scarified. Both chicory and hoary cress showed no change in viability after 35 days under water. These findings indicate that flooding is of little value in weed control from the seed-destruction angle, but it is known that many types of weed plants may be destroyed by continuous flooding for several weeks.

Effect of Fire on Viability of Seed

There is some question whether the burning over of weedy areas is effective in destroying the viability of the seed. Mature dry seeds were found to be more resistant to heat than immature ones with a higher percentage of water. Germination of Russian knapweed and wild morning-glory from seed taken from the ground after burning mature tops was greatly reduced. Thus the burning over of weedy areas may in some cases greatly reduce weeds.

Seed Viability after Passing through the Digestive Tracts of Animals and Birds

In tests with cows, calves, hogs, horses, and sheep it was found that 5 to 10 per cent of the weed seeds remained viable after they had passed through the animals' bodies. This indicates that animals feeding on hay and other food containing many weed seeds may pass many of the smaller seeds in viable condition.

Chickens and birds, on the other hand, digest the smaller weed seeds more thoroughly and are less apt to spread them. However, some seeds such as those of poison ivy, poison sumac, wild cherries, and barberries may pass through birds in a viable condition, and the seeds may thus be disseminated.

Seed Viability in Compost

It has been determined that many species of weeds will not retain their viability in properly composted manure after a period of 2 to 3 months. Such weeds include wild morning-glory, sweet clover, hoary cress, sheep sorrel, mustards, and cocklebur. It is therefore advisable not to spread fresh manure on fields without composting for 2 to 3 months if the animals have had access to weed seeds. Ensilage has been found to contain very few viable seed and so does not tend to spread weeds.

VEGETATIVE REPRODUCTION OF WEEDS

Many of our worst weed pests reproduce and spread vegetatively as well as by seeds. Most of these are perennials, but a few annuals such as hairy crab-grass and common chickweed are capable of reproducing themselves from pieces of stems.

REGENERATION DEPTHS. The depth to which roots penetrate depends on the species, the depth of the soil, the water table, and the nature of the subsoil. In most soils roots and rhizomes are most abundant in the top foot or two of soil; however, in loose, deep, well-drained soils the roots of many perennials may go down from 5 to 20 feet, depending on the weed species. The depth from which roots and rhizomes may regenerate is of great importance from the standpoint of control methods. The maximum depth from which regeneration can take place in quack-grass is 1 foot, wild morning-glory 4 feet, and camel's-thorn 30 inches. Most perennials are most easily killed in their early growth stages before rhizomes or creeping rootstocks are produced. Quack-grass 6 to 8 weeks old can be killed as easily as annual grass; and wild morning-glory with 2 to 5 true leaves is fairly easily controlled by cultivation, because the vegetative regenerative organs have not started their development by that time.

THE DISSEMINATION OF WEEDS

The methods by which weeds are disseminated have a direct bearing on their spread and on methods practiced to eradicate them. Most weeds have seeds with modifications that adapt them for dissemination by agents such as man, animals, wind, or water. The following methods are the most important ones by which weeds have been and are spread from place to place:

1. Introduced from other countries as ornamentals, herbs,

drug plants, or for other useful purposes and then escaped cultivation. Examples: Johnson-grass brought in as a forage plant, water hyacinth as an ornamental.

2. Spread as impurities in agricultural and horticultural seeds. Many weeds grow in close association with crops and have similar seeds, which facts make dissemination by this method easy (Table 43).

3. Spread in hay, feedstuffs, and bedding material that is subsequently spread in the fields as manure or as organic matter.

4. Spread by cultivating and harvesting equipment from field to field or in the same field. Examples: nut-grass and quack-grass.

5. Spread by manure containing viable weed seeds.

6. Spread in packing materials such as straw, hay, and sawdust that are shipped from different areas or countries.

7. Spread by wind. The seeds of many weeds are modified to float in the air and may be scattered for hundreds of miles by air currents. Examples: dandelion, milkweed, chicory, perennial sow thistle, Canada thistle and other thistles, ox-eye daisy, rough daisy fleabane, tumble weed, hawkweeds, wild lettuce, etc.

8. Spread by water in streams, brooks, or irrigation ditches. Seeds either float or are buoyant enough to be carried by water currents and deposited along banks over wide areas. Examples: mustards, winter cress, sedges, cocklebur, ragweeds, etc.

9. Spread by man and animals. Seeds may be modified to cling to clothes of man and to hair or wool of animals. Examples: burdocks, cockleburs, beggar-ticks, and houndstongue. Viable seeds may be spread by animals and birds in excreta. Birds may spread poison ivy, poison sumac, wild cherries, and barberries through viable seed in their excreta.

QUESTIONS FOR DISCUSSION

1. Explain the different methods of weed-plant reproduction.

2. Most weeds produce an enormous number of seeds per plant. What is the significance of this?

3. How do weeds survive unfavorable conditions that generally wipe out other crops?

4. Why aren't weeds wiped out by insects or diseases, at least in limited areas?

5. What are some of the reasons for delayed germination in weed seeds, for more than 60 years in some cases?

6. Why is it a bad practice to plow under weeds that have matured seeds?

7. Under what conditions might crop cultivation for weed control be considered a poor practice?

8. Why does Table 42 indicate the futility of eradicating certain established weeds by crop rotation?

9. How long may weed seeds retain their viability under water?

10. At what stage is weed seed least resistant to heat from a fire?

11. What evidence is there that weed seed may be spread by manure?

12. Which is more apt to have viable weed seed in it: chicken manure or cow manure? Fresh manure or well-rotted manure?

13. How long do seeds stay viable in composted organic matter?

14. From what soil depths will most weed seed germinate?

15. From what depth will roots or rhizomes of perennials regenerate?

16. Why are perennials more easily killed when they are 1 to 2 months old than when they are 1 or more years old?

17. Explain the various ways by which weeds or their seeds may be disseminated.

18. What are some seed modifications for the purpose of dispersal?

Chapter 21

THE ELEMENTS OF WEED CONTROL

Weed control today ranges all the way from ancient hand pulling and hoeing to modern chemical treatments by airplane. Whatever methods are used, however, the chief aim should be to prevent weeds from gaining a foothold on the soil. Like plant diseases and insect pests, weeds are more easily prevented than controlled once they have established themselves.

Weed control must be carried on conscientiously to be successful. The weed-control program should be fitted to needs and conditions using recommended control measures. New weeds should be eradicated without delay to prevent their spread. Cooperation with neighbors is essential, especially in controlling such wind-borne weed pests as Canada thistle, perennial sow thistle, and dandelion.

PRINCIPLES OF WEED CONTROL

Effective elimination of weeds is based on observing the following fundamental principles:

1. Prevent weed seeds from being carried to one's fields.
2. Prevent perennials from making topgrowth.
3. Prevent weeds from going to seed on the farm.
4. Maintain optimum soil fertility and chemical reaction for the crops grown.
5. Adjust cropping system and crop rotation to discourage completion of weed life cycles.
6. Use proper cultivators and harrows to destroy the weeds, and time their use for maximum effectiveness.
7. Use chemical weed destroyers with the proper application equipment and timing when conditions warrant their use.

PREVENTION OF INTRODUCTION OF WEEDS AND WEED SEEDS

Weeds may be brought into new areas with soil around the roots of plants, with manure from animals, with stock feeds, with mulching material, and as impurities in crop seeds (Table 43). Some weed seeds are nearly always present in grain, clover, and grass seeds. Only a few seeds are necessary to produce enough plants to act as a center of distribution through the harvested seed crop or through the various natural agencies that may spread the seeds.

Many states have pure seed laws to help the conscientious growers keep their places weed free. These laws generally require the name and address of the seed dealer or grower, the kind of seed and percentage of germination, the minimum percentage of purity, and a guarantee that no primary noxious weed seeds are or that a definite, limited amount is present. Many states also have seed laboratories equipped to make purity tests of seed for the farmer.

In addition, the Federal Seed Act of 1940 controls the quality of all imported agricultural and vegetable seed and requires the correct labeling of all seed in interstate commerce so that it complies with the seed laws of the state into which it is transported.

It is important that growers know what constitutes high-grade seed and that they should be willing to pay higher prices to obtain it. Seed containing a high percentage of weed seed is actually the most expensive kind that can be purchased, since the crop of weeds introduced with it adds greatly to the labor problem, reduces the crop, or, if it is a seed crop, greatly lowers its value.

TABLE 43

WEED SEED COMMONLY FOUND IN CROP SEED

Bracted plantain
Buckhorn plantain
Canada thistle
Dodders
Foxtails
Lambs-quarters
Pigweeds
Quack-grass
Ragweeds
Russian thistle
Sheep sorrel
Shepherds-purse
Smartweed
Sour dock
Wild morning-glory
Wild mustard

WEED AND WEED SEED DESTRUCTION BY CULTURAL PRACTICES

Preventing the production of weed seeds is the principal method of attack against annual and biennial weeds and helps confine perennials to definite areas until they may be wiped out.

CUTTING WEEDS. Weeds along roadsides, in fencerows, and in waste places should be cut about three times during the growing season to prevent them from going to seed. Hay should be cut early for the same reason.

ENCOURAGING WEED-SEED GERMINATION. Weed seeds should be encouraged to germinate by being left near the soil surface instead of being plowed under. Seeds of most weed species germinate only in the top inch of soil. Plowing under long-lived weed seeds prolongs their germination over many years, because each subsequent cultivation brings some near to the surface. Disking and harrowing the fields after weeds have had a chance to germinate and before the crops are planted destroys many weeds. Once a crop is in, only shallow cultivation should be practiced, so as not to drag more weed seed near to the surface.

STARVING PERENNIALS. On cultivated land, biweekly cutting of the tops of perennial weeds just below the ground surface, with the duckfoot type of cultivator, not only prevents seed production but also starves out the roots. One year of this practice is sufficient for most perennials, providing dormant seeds are not buried in the soil; but some, such as Canada thistle and wild morning-glory, may require 2 years of such starvation.

USE OF ANIMALS IN WEED CONTROL. Certain species of weeds in pasturelands may be effectively controlled by livestock that will feed on them. Sheep will eat ragwort, oxeye daisy, wild morning-glory, sheep sorrel, buttercups, and dock species, whereas cattle will not touch them. One method of controlling perennial sow thistle is to plow the weeds up in the spring and turn sheep loose on the fields for summer fallow. Goats have been effective in clearing brushland. They will also feed on wild blackberries, gorse, and many herbaceous weeds.

PASTURE ROTATION. Grazing grasses must be allowed to make a good topgrowth at some time during the growing season in order to help produce a strong root system. This in turn will make possible a vigorous topgrowth that will crowd out weeds. Close and continuous grazing on pastures results in a weak grass sod in which weeds easily become established, because any condition that allows light to penetrate to the ground surface tends to produce an environment favorable for the germination of weed seeds. Many weed seeds in pastures remain dormant unless there is adequate light intensity. To avoid overgrazing and to stimulate topgrowth, pastures should be rotated so that for some period (a month or more) during the growing season no animals are placed in them. Mowing the weeds that shade the grasses two or three times a season also helps produce a better growth of desirable grasses.

TIMING OF PLOWING AND CULTIVATING. A practical control for weeds that mature their seeds late in the season, such as cocklebur, ragweeds, sandbur, and beggar-ticks, consists in early plowing after harvesting of early maturing crops of small grain. The land should be allowed to lie fallow, with frequent diskings or harrowing, to encourage dormant seed to germinate so that they may be killed by subsequent cultivations. On land infested with early maturing weeds, late-planted crops should be grown, so that the weeds may be killed by cultivation before the main crop is planted. Heavy infestations of perennials such as wild morning-glory, climbing milkweed, and ground-cherries can be controlled by planting small grains, then by early plowing and eventually by alfalfa.

CROP ROTATION. In many cases the proper succession of crops helps in the control of weeds. For example, wild carrot and chicory prevalent in meadows and pastures may be controlled by plowing and growing several successive, clean-cultivated crops and then reseeding. Marsh cress, penny cress, and downy brome-grass (winter annuals) are easily controlled by spring plowing, after which corn or soybeans are grown under clean cultivation.

CONTROL OF PERENNIALS BY SUMMER FALLOWING. Summer fallowing must be carried out systematically with biweekly cultivations to prevent topgrowth of perennials and to starve the roots. Most weeds can be killed by 1 season of summer fallowing, but a few of the most persistent ones like wild morning-glory and hoary cress may require more than

1 season. One or two missed cultivations may revive the weeds to such an extent as to make control measures appear ineffective. Summer fallowing may be followed by smother crops such as alfalfa, sorghum, millet, Sudan-grass, drilled soybeans, drilled corn, vetch, sweet clover, winter rye, or winter wheat to prevent any seedlings from taking hold. The smother crop best fitted to the soil and the region should be selected.

SMOTHERING WEEDS. A few other methods of weed control applicable only on small areas can be practiced successfully. Mulching plants with 3 to 4 inches of straw, salt hay, ordinary hay, well-rotted manure, or sawdust will smother annual weeds or shallow-rooted perennials that are not up and will make for more favorable growing conditions. Deep-rooted perennials cannot be smothered by mulching, since they will grow through a deep layer of mulch. It is important that this mulching material be free of weed seeds to prevent a new weed problem from being created. Special mulching paper can be purchased; it is laid down between the crop rows and effectively prevents weed growth in the area that it covers.

Tillage Equipment and its Use

Cultivators, depending on their design, destroy weeds by three methods: (1) uprooting the seedlings or larger plants; (2) covering the weeds and smothering them; (3) cutting off the aerial parts from the root system.

For most perennial weeds, the duckfoot type of cultivator shovels or cultivator sweeps is recommended. For the high speeds of modern tractors (5 to 6 miles per hour), sweeps with a broad angle and low crown are preferable, since they throw very little soil and leave a smooth, uniform surface that is highly desirable if flame or chemical weed control is to follow. It is best to set cultivator sweeps in the shop according to a floor-line plan of the crop rows, because better results are obtained than if one attempts to set them in the field. The sweeps should be set flat on the floor of the diagram so that their angles will all be parallel to the surface during cultivating. They will then stay sharp, to cut off the aerial parts just below the soil surface.

For perennials such as quack-grass and devils shoestring, repeated use of a field cultivator equipped with quack-grass points is considered better, since it pulls to the surface and exposes to drying the shallow rhizomes or creeping rootstocks of these plants. For the control of annuals in the spring before a crop is put in, repeated harrowings with a disk or a spike-toothed harrow or both arranged in tandem destroys the majority of germinating weed seeds. Cultivators with sweeps for hilling up crops such as potatoes and corn help control weeds in the crop rows by smothering them. To be effective, this must be done while the weeds are still small. It has been determined that cultivators other than those with broad-angled, low-crowned sweeps do their best work at speeds from 2 1/2 to 4 miles per hour. The timing of cultivations should generally be determined by the stage of weed growth in each crop. Biweekly cultivations are usually necessary to get the weeds while they are small.

Flame Cultivation of Weeds

With the recent adaptation of the liquefied petroleum gases, butane and propane, as fuels and with a suitable nozzle-type burner, selective flame cultivation has become practicable for crops such as cotton, sugar cane, corn, and woody deciduous nursery plants. The cost of the fuel amounts to as little as 60 to 70 cents per acre, considerably less than the cost of hand hoeing. The flaming equipment requires level ground, careful adjustment, and a certain skill which comes only with experience on the part of the operator. The spray-nozzle burner is set at a 45^0 angle to the base of the plants and is adjusted so that the flame strikes the drill about 1 inch from the plants. There are usually two burners per row, facing each other but staggered, so that the flames do not meet. The speed of movement of the flaming device should be such that searing of the weeds is accomplished without harm to the larger- or tougher-stemmed cultivated plants. The size of the nozzle orifice used in the burner may be varied to conform with the size of the plants, the number of weeds, and the pressure. Pressures may vary from 30 to 40 pounds per square inch, but 50 pounds may be necessary for penetration of the flame in heavy weed mats and for higher speeds. Since flaming is practicable only on small weeds, the number of flamings necessary for a crop is usually determined by seasonal weather conditions. Cotton should be at least 6 to 8 inches tall and 3/16 inch in diameter at ground line for first weed flaming. Sugar cane can be flamed for weeds the first time when it is from 4 to 6 inches tall.

QUESTIONS FOR DISCUSSION

1. Why has progress in weed control been so slow until recently?
2. Weeds may do as much damage as insect pests and plant diseases combined, yet growers usually do not let the presence of weeds excite them. Can you offer any explanations for this?
3. Is there any hope for the complete eradication of a weed species from the earth? From a limited area?
4. What are some of the ways in which weeds may become established in a given area?
5. Why isn't more done to prevent the growth of weeds?
6. Are our present agricultural methods conducive to the creation of weed problems?
7. Why should weed control be a community effort?
8. What are some of the ways that weed seed may be carried into new areas?
9. Why should weed control begin with the prevention of weed-seed production?
10. Of what importance are the pure seed laws of many states?
11. Why is cheap seed usually more costly in the end than more expensive seed?
12. How do weed seeds get into crop seeds?
13. Why is plowing under weeds that have gone to seed a bad practice?
14. Why should weed seeds be encouraged to germinate?
15. Which is best for weed control: shallow or deep cultivation?
16. What happens when the tops of perennial weeds are periodically cut off below the ground?
17. Why is overgrazing conducive to weedy pastures?
18. How does crop rotation help in the control of weeds?
19. What is the purpose of a smother crop? A heavy mulch?
20. What are some of the advantages and disadvantages of flame cultivation?
21. What crops lend themselves best to flame cultivation? Why?

Chapter 22

CHEMICAL METHODS OF WEED CONTROL

Until recently weed control consisted largely of hand and machine cultivation with great expenditures of labor, time, and money in this field of plant protection. The discovery of 2,4-D and its selective action has given weed control the same impetus that Paris green gave to the science of economic entomology and that Bordeaux mixture gave to the science of plant disease control more than half a century ago. This recent discovery of new chemicals with selective action against weeds and the development of efficient application equipment has awakened interest in chemical weed control and is creating a new field of science dealing specifically with weeds and their control. Chemical weed control is an excellent supplement to mechanical tillage and is proving successful where mechanical control methods are impractical or impossible.

PRECAUTIONS IN CHEMICAL WEED CONTROL. This field of science is so new that the long-range effects of various materials on plants, soil, and soil organisms and the response of these materials to various soil and climatic conditions are not fully known as yet. Also there is still much to be learned about the life cycles of many weeds and their response to environmental factors.

Caution in the use of new herbicides is advised until more is known and definite recommendations are made by state and government experiment stations.

CLASSIFICATION OF CHEMICALS USED IN WEED CONTROL. The chemicals used in weed control (herbicides) may be divided into (1) the non-selective contact herbicides; (2) soil sterilants; (3) the selective contact herbicides; and (4) the pre-emergence contact and residual herbicides. Some of the herbicides may fall into two or more of these categories. Selective herbicides are discussed in Chapters 23 and 24.

THE NON-SELECTIVE CONTACT HERBICIDES

Non-selective contact sprays or dusts are those that kill the topgrowth of plants regardless of the species. They may or may not be translocated and are applied with or without wetting agents, depending on the nature of the foliage to be wetted. Wetting agents are employed only when hard-to-wet foliage is sprayed or when spray volume is much reduced. Non-selective contact herbicides are various types of oils, oils plus other herbicides, sodium arsenite, sodium chlorate, ammonium sulfamate, and ammonium thiocyanate. Their dosages and uses are listed in Table 44.

OILS. Oils may cause two types of injury to plants. Chronic injury is caused by heavy, unrefined oils with a high percentage of unsaturated hydrocarbons (lubricating and motor oils), and their application results in slow death to nearly all parts to which they are applied. Acute injury is related to the chemical composition of the oil and is correlated with high aromatic content such as that of light oils of the Stoddard-solvent or fuel-oil type. Their uses are given in Table 44.

SODIUM ARSENITE. This arsenical is usually employed in dilute solution when complete contact killing of weeds is desired at little expense and where there is no hazard to humans and livestock from this highly poisonous material (Table 44). Its continuous use should be discouraged under dry conditions, because a toxic residue may build up in the soil and render it sterile (see further discussion under soil sterilants).

SODIUM CHLORATE. This chemical may be used as a contact herbicide on foliage and as a soil sterilant to destroy plant roots. As a contact herbicide it is particularly effective in the destruction of perennials, since it has the ability to kill the tops and also to work down into the roots, gradually killing them. Deep-rooted perennials may require two to three treatments before they are killed.

One of the chief disadvantages of sodium chlorate is that it may create a dangerous fire hazard, because it becomes very inflammable when it dries on organic matter. Livestock should be kept away from treated areas until after a rain, because sodium chlorate is poisonous. In addition, it should not be used near valuable trees or shrubs, since defoliation and death of the plants may occur.

Because of the expense of treatment, sodium chlorate is recommended only for small areas of perennial weeds where a quick kill and complete eradication are desired and where soil sterility up to 2 or 3 years is not objectionable. It is not desirable where soil sterility would result in serious soil erosion or in loss of an established stand of perennial grass.

Poor results have been obtained with weeds on alkaline soils (see further discussion under soil sterilants).

The following precautions should be observed with sodium chlorate:

1. Keep in tightly closed metal containers when not in use.
2. Wear rubber boots when spraying.
3. Do not use near buildings.
4. Keep solution off clothing, but if clothing is saturated, take it off before it dries and wash before wearing again.
5. Wash equipment and rinse it thoroughly after using.
6. Do not spray during hot, dry periods.

AMMONIUM SULFAMATE. This chemical salt, sold under the trade name Ammate, has distinct toxic properties for killing certain woody plants, both as a foliage spray that is translocated into the roots of many plants and as a dry salt applied to the cut surfaces of tree and shrub stumps.

It has the advantage of creating no fire hazard, leaving no poisonous residue in the soil, and being non-poisonous to livestock; however, it has the disadvantage of being costly per treated area, corrosive to metal, and harmful to grasses. Since it does not injure trees and shrubs as long as it is kept off the foliage and green twigs, it is useful in controlling certain weeds under them or on their trunks. It does not give good control of herbaceous perennial weeds and grasses. Applications at the most favorable growth stages for weeds (usually during June) have been found most effective.

AMMONIUM THIOCYANATE. This compound, a by-product of the coke industry, is very toxic to plants. It is a crystalline substance, soluble in water, non-caustic to the skin, non-inflammable, and distasteful to livestock. It is not highly poisonous to man or animals but should be used with caution under trees. Its present cost limits its use to small areas, but it is an effective herbicide for quick contact kill or for shallow soil sterilization.

TABLE 44

NON-SELECTIVE CONTACT HERBICIDES

Herbicide	Dosage	Uses
Oils Diesel, stove, aromatic, lubricating, kerosene	150-500 gal. per acre	Annuals and perennials along railroad rights-of-way, roadsides, fencerows, canal banks, etc.
Oils plus 2,4-D, dinitro compounds, pentachlorophenol, sodium pentachlorophenate	Same as above or mfr's directions	Same as above but more effective
Sodium arsenite (spreader+10-20% diesel oil increases effectiveness)	1-5 lb. per 25 gal. water per sq. rd.	Annuals and shallow-rooted perennials along railroads, in parking areas, driveways, tennis courts, etc; mesquite stumps (applied to sapwood)
Sodium chlorate (Atlacide)	2-7 lb. in 25 gal. water per sq. rd.	Annuals, perennials, barberries, poison ivy, cottonwood stumps (applied to sapwood)
Ammonium sulfamate (Ammate)	1 lb. per gal. of water on foliage; 2-4 oz. per 6 in. of stump diameter. For barberry, 1/3 lb. on cut crown, cover with soil.	Woody plants, poison ivy, tree and shrub stumps (on cut surfaces), sprout growth of scrub oak, hazel, sage-brush, cut barberry bushes
Ammonium thiocyanate	1/2-2 lb. per gal. of water per sq. rd.	Kills foliage of weeds

SOIL STERILANTS

Soil sterilants may be divided into those that are temporary and volatilize or decompose rapidly leaving no injurious residue; and those that stay effective for long periods (semi-permanent), preventing any plant growth while their residue remains. They destroy growing plants, weed seeds, or both, and render the soil barren during their effective period.

Semi-Permanent Soil Sterilants

The semi-permanent soil sterilants consist of chemicals such as sodium arsenite, sodium chlorate, boron compounds (Borascu, borax), and common salt (Table 45). When they are applied in heavy doses for the control of perennials their action is chiefly through the roots. At present they are used mainly where permanent soil sterilization with no vegetation is desired, such as on railroad beds, parking lots, driveways, tennis courts, and fire lanes. Their permanence depends on factors such as leaching of the chemical, soil reaction, soil fertility, weather, concentration applied, and rate of decomposition.

SODIUM ARSENITE. This chemical is one of the best permanent soil sterilants. Light soils fix the least amount and heavy soils the greatest amount of sodium arsenite; thus light soils may be expected to be leached of the chemical most quickly.

Weed species vary in their resistance to arsenic poisoning because of root depth and protoplasmic resistance. Shallow-rooted plants are most easily killed, especially if heavy rains follow application, to cause leaching to lower levels. Deep-rooted perennials tolerate high salt concentrations and are not easily killed by sodium arsenite.

WHITE ARSENIC. White arsenic is also promising as a permanent soil sterilant, because it is relatively insoluble in water, but it slowly develops a toxic concentration in the soil within a year or more. Its toxic residues last longer in the soil than those of sodium arsenite.

SODIUM CHLORATE. For soil treatment sodium chlorate is best applied as the dry salt, since in that form it is easier to handle and is less of a fire hazard. It has been determined that less sodium chlorate is generally needed in infertile soils than in highly fertile soils, and that the higher the nutrient content of the soil the less effective are the chlorate treatments.

Sodium chlorate is freely mobile in the soil so that applications of the dry salt are readily leached downward by watering or rain. Thus its distribution is mainly determined by the amount of water that passes into and through the soil after the chemical is applied. Applications of the salt are most effective in the fall or winter when soil nutrients are at their lowest level. Generally, shallow-rooted weeds are more easily killed by sodium chlorate than deep-rooted weeds, but heavy rainfall after application may make the reverse true. Flax and oats are most tolerant of chlorates in the soil and can generally be planted the spring following fall treatment.

BORON COMPOUNDS. Boron compounds in the form of borax or Borascu are effective in soil sterilization in proportion to the amount of elemental boron applied and in the amount of leaching or fixation that takes place. Boron compounds are not subject to chemical decomposition in the soil. Toxicity to plants varies greatly and tends to be greatest in soils of coarse texture. Boron is very toxic to some shallow-rooted plants and is almost harmless to others, especially to grasses that may completely take over treated land. It loses its potency through leaching soon after application and is useful only where a material relatively non-poisonous to man and animals is required, such as on playgrounds, in parks, etc. It is usually applied in dry form during seasons when rain will wash it down to the roots of weeds.

COMMON SALT (Sodium chloride). This common chemical, when obtainable as crushed rock salt or as ordinary ground salt at a low price, and when applied completely around the base of the plants, has been found useful in killing poison ivy, poison sumac, and barberry bushes. The exact amount depends on the size of the bush. Sodium chloride as a selective beet spray is discussed in Chapter 24.

Temporary Soil Sterilants

Temporary soil sterilization is used chiefly to destroy perennial weeds on agricultural lands, whereas semi-permanent soil sterilization is used to prevent all growth where such growth is undesirable. With weed killers that act through

TABLE 45

SEMI-PERMANENT SOIL STERILANTS

Soil Sterilant	Dosage	Persistence in Soil	Uses
Sodium arsenite and white arsenic	2–8 lb. per sq. rod on light soils, 8–12 lb. on heavy soils	Several years	Shallow-rooted weeds
Sodium chlorate	2–10 lb. per sq. rod. (depending on weed susceptibility and soil)	6 months to 3 years	All types of weeds
Boron compounds (borax, Borascu)	8–30 lb. per sq. rod (may be combined with sodium chlorate for added effectiveness)	Several months or more under dry conditions	Sandy soils: playgrounds, parks, etc. for Klamath-weed, bear mat, poison ivy
Salt (sodium chloride)	2–20 lb. per plant	Several years under dry conditions	Poison ivy, poison sumac, barberry bushes

TABLE 46

TEMPORARY SOIL STERILANTS

Soil Sterilant	Dosage	Persistence in Soil	Uses
Ammonium thiocyanate	4–10 lb. per sq. rod	2–4 weeks	Annuals, kills back herbaceous and woody perennial growth
Chloropicrin (Larvacide)	3–4 cc. per sq. ft. or 10.5 lb. per 1000 sq. ft.	2–4 weeks	Perennial weeds on agricultural lands, weed seeds
Carbon disulfide	10 cc. per sq. ft. or 24.1 lb. per 1000 sq. ft.	4–6 weeks	Deep-rooted perennials in summer
Methyl bromide	1 lb. per 100 sq. ft. or 2 lb. per 100 cu. ft.	About 3 days	Weed seeds
Sodium trichloroacetate (TCA)	70–140 lb. acid equivalent per acre in 100–200 gal. water	2–3 months or more	Established annual grasses, also Johnson-grass, quackgrass, Bermuda grass, prickly pear cactus
Sodium trichloroacetate (TCA)	10–20 lb. acid equivalent per acre in 20–40 gal. water	2–3 months	Grass seedlings in 2- or 3-leaf stage

the soil it is important that the chemical in lethal concentrations reach the rootstocks and roots and that it remains long enough to kill all roots before it leaches out or decomposes. Some of the factors that govern the effectiveness of temporary soil sterilants are period of toxic action, soil type, soil moisture, and soil temperature (see Table 46 for dosages and uses).

CHLOROPICRIN. The characteristics and uses of this material have been discussed under insecticidal and fungicidal soil treatments. Because of the expense of treating large areas ($400-$500 per acre), its use is limited to compost soil, greenhouse soils, coldframes, and small field areas. It will control nut-grass as well as destroy weed seeds in the soil. Its use as a herbicide is practical only when it is used in conjunction with soil sterilization for soil disease or nematode control.

CARBON DISULFIDE. This is a colorless, volatile liquid that vaporizes readily to produce a very toxic gas heavier than air. The chemical is very inflammable and explosive and must be used with extreme caution.

The soil should not be too wet for gas diffusion and should be sealed by moistening the top soil to prevent too rapid loss of gas. Because of lack of diffusion, it is not very effective in heavy clay soils. Cost of the chemical makes it impracticable on large scale.

METHYL BROMIDE. This odorless, volatile liquid previously discussed in connection with nematode and disease control has been found very effective in the control of weed seed in the soil when the gas is confined at the recommended dosages for 24 hours. It also kills the rhizomes of perennial grasses such as quack-grass and Johnson-grass. The soil should be of normal moisture content and pulverized. A gas-tight tarpaulin is placed over the area to be treated and is held off the ground by a center ridge-pipe placed 12 to 18 inches above the ground. The edges of the cover are sealed with soil and the required amounts of fumigant piped under the cover at the proper intervals with a special methyl bromide applicator. If soil temperatures are between 50 and 60° F., the exposure time should be doubled. A specially built fumigation chamber is very handy for treating small amounts of soil.

SODIUM TRICHLOROACETATE (Sodium TCA). This is a dry, crystalline, water-soluble chemical that has shown considerable promise in the control of established annual grasses as well as of certain perennial grasses. Its toxicity to man and animals is about the same as that of table salt, but it is irritating to the skin and eyes and is corrosive to metals. It is partially selective on the foliage of plants, and when applied to the soil it acts mainly through the root system, inhibiting seedling growth of grasses much more than that of dicots. Its killing action on perennial grasses is slow, because it may take 2 to 3 months for the death of rhizomes. Higher dosages are required to kill Johnson-grass on which foliage applications are usually more effective. Moist conditions increase the effectiveness of sodium TCA, but heavy rains after treatment may readily leach the chemical and produce poor results. Late summer or fall applications are best on land where crops are to be planted next spring. Sodium TCA may be used in combination with 2,4-D and 2,4,5-T formulations in water and with emulsifiable pentachlorophenol and dinitro formulations.

QUESTIONS FOR DISCUSSION

1. Should mechanical methods of weed control be discarded for chemical methods?
2. What are the advantages and disadvantages of chemical weed control as compared to mechanical and cultural methods?
3. What are the factors that make a weed killer useful?
4. Where are non-selective contact herbicides useful?
5. Oils may produce either chronic or acute injury to weeds. What determines their mode of action?
6. Under certain conditions sodium chlorate is a translocated herbicide. What does that mean?
7. What are the different ways of applying chemicals for weed control?
8. What should determine whether one uses cultural, mechanical, chemical, or no weed control at all on a given crop?
9. Why are translocated herbicides best for woody and herbaceous perennial weeds?
10. What factors affect the performance of soil sterilants?

11. Why do weeds of desert or arid regions tend to be tolerant to high salt concentrations?

12. What are the dangers involved in the use of soil sterilants?

13. Why do fumigants tend to be more efficient soil sterilants than chemical solutions or suspensions?

14. What should be the preparation and condition of a soil for most effective chemical sterilizing?

15. What soil sterilants have also been found useful for soil insect, disease, and nematode control?

16. Chloropicrin for soil sterilization is used at the rate of 600 pounds per acre. What should the dosage be for 1000 square feet? For 100 square feet?

17. Why is a contact, non-translocated herbicide more effective for annuals than for perennials?

Chapter 23

SELECTIVE HERBICIDES

Two general methods of chemical weed control for crops are recognized: (1) post emergence weed control—chemical control applied to weeds after the crop has emerged from the soil; and (2) pre-emergence weed control—chemical control applied after the crop is planted but before it emerges from the soil. In pre-emergence control the weeds should or should not be up as determined by the chemical to be used. In post-emergence weed control the chemicals used must be selective. The term selective applies to chemical weed killers that can be applied to destroy weeds without any permanent detrimental effect to the crop in which the weeds are growing. Selective herbicides may either kill by contact or be translocated, producing death to all parts. Some chemicals have a selective action only on the stems of certain crops and will severely injure the foliage. In such cases special directional nozzles may be used to confine the spray to the plant bases and the weeds. Selective herbicides may be used as general non-selective weed killers where crops need not be considered.

REASONS FOR SELECTIVE ACTION. Selective action may be due to differences in structure and nature of the surfaces of plants or to differences in their physiological make-up. Most grasses and grains are not as susceptible to weed killers as broad-leaved weeds. Waxy-leaved plants with a thick cuticle, such as peas, asparagus, alfalfa, and red clover, resist the action of certain weed killers better than the weeds among them. Likewise, not all weeds are equally susceptible to selective weed killers.

CONSIDERATIONS IN APPLYING SELECTIVE HERBICIDES. The important points to consider in applying a selective herbicide are:

1. The nature and stage of growth of the crop.
2. The species of weeds present.
3. The stage of growth of the weeds.
4. Environmental factors influencing the rate and vigor of the weed growth.
5. Weather conditions at the time of application and immediately following.
6. Dosage applied to a given area.

In applying a selective herbicide, it is essential to know not only the resistance of the crop in general to the herbicide, but also whether the particular variety involved is resistant. There are many instances where there are great differences in varietal resistance to selective weed killers, and considerable damage to a particular crop variety may occur. The stage of growth of the crop should also be considered, because its resistance to damage varies during its growth stages. Cereal grains are best sprayed when they are approximately 6 inches high, during the full tiller stage but before booting.

Weeds are most susceptible when they are small and growing rapidly. Early application, therefore, results in better control with less chemical and increased yields because of the early destruction of the competing weeds. The larger and older the weeds the higher the concentration needed to kill them. Summer annuals such as lambs-quarters, pigweeds, cocklebur, and sunflower should be sprayed when they are less than 4 inches high. Winter annuals such as various mustards, fan-weed, yellow star-thistle, and wild radish are most easily killed while they are still in the rosette stage. Usually weeds growing rapidly under optimum conditions are relatively susceptible, whereas those growing under adverse conditions tend to be resistant to herbicide sprays.

High humidity adds to the effectiveness of herbicides such as iron sulfate (ferrous sulfate), copper sulfate, the dinitro weed killers, and calcium cyanamid. Diffusion of the herbicides into the weed tissues is directly correlated with temperature—greater penetration takes place on warm days than on cool days.

There is no significant difference in effect from the amount of water for diluting the 2,4-D weed killers, providing the same amount of chemical is distributed evenly over a given area. Because of this fact, low-pressure, low-volume spraying equipment is becoming increasingly popular, and 10 gallons of spray per acre is a standard application.

USING 2,4-D (2,4-Dichlorophenoxyacetic Acid) COMPOUNDS

A wholly new concept of weed control has arisen since the striking effects on plants of the growth-regulating substance 2,4-D were announced in 1944. The compounds of 2,4-D are cheap, selective, easy to apply, and adapted to a wide range of problems. The effectiveness of 2,4-D in minute quantities makes it economically sound for weed control on large areas, with a great saving in labor and cost and with corresponding crop increases. The value of this chemical in weed control is derived from the fact that it is harmful to many weeds but is harmless or relatively harmless to some cultivated crops. Minute quantities in contact with plant tissues may be absorbed and translocated to all parts of the plant, causing striking changes in the form and functions and often resulting in their death. From the feeding experiments conducted to date, no harmful effects on man or animals are to be anticipated from eating plants sprayed with 2,4-D.

How 2,4-D Affects Plants

The hormone-like compound, 2,4-dichlorophenoxyacetic acid (2,4-D), is ordinarily very slow acting and kills by upsetting the growth mechanism of plants. The most evident effects are bending, twisting, and sometimes cracking of the stems (Fig. 190); thickening, curling, and stringiness of leaves, with gradual color change to yellow or red and brown (Fig. 191); and finally death of susceptible plants including the roots. These symptoms in some plants are not unlike severe symptoms of a virus disease such as shoe-string of tomato, and care must be taken not to confuse the effects of this weed killer with a virus disease. The effects of 2,4-D on weeds usually show up in 3 to 4 days, but death of susceptible plants may not occur for 2 to 8 weeks or more, depending on weather conditions. Plants die more rapidly in hot weather than in cool weather when they are treated with 2,4-D.

Formulations of 2,4-D

The 2,4-D acid is a white powder, and, since it does not dissolve readily in water, it is usually put on the market in the form of soluble salts and esters with a stated 2,4-D acid equivalent content. Three general types of 2,4-D preparations are on the market: (1) the metallic salts; (2) the amine salts; and (3) the esters.

THE 2,4-D SALTS. Sodium and ammonium salts of 2,4-D are available as white powders that are only moderately soluble in water.

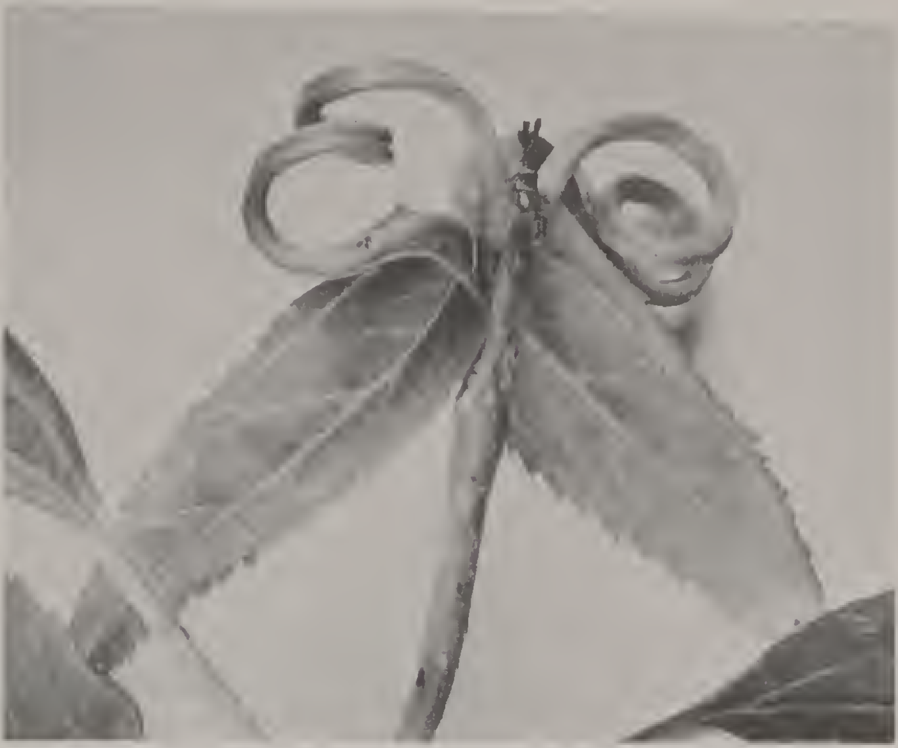


FIG. 190. 2,4-D injury to forsythia. Note twisted leaf petioles.

THE AMINE SALTS OF 2,4-D. The diethanolamine salt and the triethanolamine salt are both sold as dark-colored water solutions. They are easy to handle and quicker acting but produce about the same final effects on plants as the metallic salts.

ESTERS OF 2,4-D. Esters are made by combining the 2,4-D acid with an alcohol. Ethyl, amyl, isopropyl, butyl, and several new higher esters of 2,4-D are on the market. All are about equal in their effects. They are marketed as oil solutions that form milky emulsions with water. The esters, with a few exceptions, vaporize more readily than the salts and therefore require greater care in use, because the vapors are capable of harming sensitive plants as much as or more than a half a mile away.

DUSTS OF 2,4-D. Dusts made out of 2,4-D compounds are not recommended since great care must be taken to avoid drift of dust onto valuable plants. Damage has been reported several miles away from the careless use of 2,4-D dusts. Airplane dusting with 2,4-D has presented such a damage hazard to adjacent sensitive crops that its application by this method has been banned by order of the Federal Government.

COMPARISON OF METALLIC SALTS, AMINE SALTS, AND ESTERS OF 2,4-D. When these formulations are compared on the basis of equivalent weights of acid, the esters are the most effective form of 2,4-D and consequently most hazardous to crops; the metallic salts are the least effective, and the amine salts are intermediate. The different forms of 2,4-D, when applied as pre-emergence applications, show less difference in their toxic action on weeds.

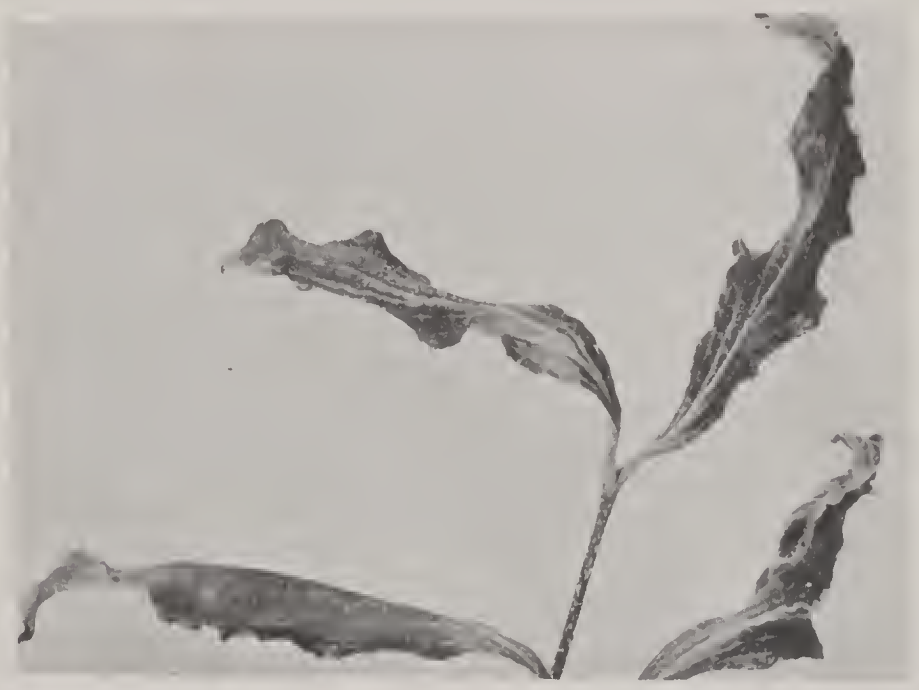


FIG. 191. Curling and distortion of dogwood leaves, caused by 2, 4-D injury.

The Effect of 2,4-D on Different Kinds of Plants

Both weed and crop plant species show marked differences in their reaction to 2,4-D. Some plants may be killed by slight traces of 2,4-D, whereas others cannot be seriously injured by high concentrations. This difference in susceptibility holds for both weeds and crop plants and determines whether 2,4-D applications are advisable and practical (see Table 47).

GRASSES. Those beyond their seedling stages, in general, are highly resistant to 2,4-D. The creeping bent grasses are an exception and are injured by 2,4-D. Grass weeds, therefore, cannot be effectively controlled by post-seedling applications of 2,4-D, but broad-leaved weeds growing in grass crops may generally be controlled without harm to the crop.

ANNUAL AND WINTER ANNUAL WEEDS. Most species of broad-leaved weeds are highly susceptible to 2,4-D treatments and can easily be eradicated; some are somewhat intermediate in susceptibility, and a few such as corn cockle show a high degree of resistance. In general, all are much more susceptible in their seedling stages.

BIENNIAL AND PERENNIAL WEEDS. These weeds vary widely in their response to 2,4-D. Dandelion and plantains are most easily killed, whereas curly dock which also possesses a taproot is much more resistant. Perennials with creeping rhizomes or roots, such as Canada thistle and wild morning-glory, can be killed above ground, but repeated applications to the regrowth are necessary to finally kill the roots and rhizomes. Repeat treatments should not be applied until the new growth is active. Russian knapweed and water smartweed are so resistant that even the topgrowth is hard to kill.

In most cases, one annual treatment with 2,4-D under favorable conditions will prevent perennials from producing seed and will delay regrowth from 1 to 3 months.

WOODY WEED PLANTS. The ester forms of 2,4-D and 2,4,5-T combined (see Chapter 24) can be used for effective defoliation or killing of many vines, shrubs, and trees. In many species they will kill all woody tissue back to the ground, and even the roots. Some species, however, may sprout again from dormant buds below the affected areas. Many woody brush species may be killed in any season, including the dormant one, by cutting the stems near the ground level and applying a 2 to 4 per cent (W/V) 2,4-D and 2,4,5-T ester dilution in fuel oil to the freshly cut stump surfaces and bark.

Generally, the best method of killing thick brush on rights-of-way consists of cutting it down and spraying the sprouts, when they reach a height of 1 to 3 feet are are growing actively, with a water dilution of the esters of both 2,4-D and 2,4,5-T at high enough pressures and volume to wet the foliage and stems thoroughly.

CROPS AND ORNAMENTAL PLANTS. Most broad-leaved crop and ornamental plants such as legumes, most vegetables (except corn and asparagus), garden flowers, shrubbery, cotton, grapes, tomatoes, and tobacco are either killed or severely damaged by 2,4-D even at low dosages. 2,4-D can be used effectively and economically as a selective weed killer in grass-type crops such as cereals, hay, lawns and sods, and grass pastures without serious damage to the crops themselves. Creeping bent lawns may be injured by 2,4-D treatments. Some sensitive vegetables may have the soil around them treated for weeds providing they are well covered by Hotkaps.

Rates of Applying 2,4-D

The dosages of 2,4-D may be expressed in two ways: for large areas dosage is usually expressed in pounds of 2,4-D acid per acre; but for small areas it is more convenient to express it as the number of gallons of a certain percentage solution by weight per square rod. The actual amount of solution applied per acre is of little importance providing the necessary amount of 2,4-D is applied uniformly and thoroughly over the vegetation. The new high-concentration, low-pressure equipment applies evenly as little as 5 gallons of a concentrated solution per acre. Low-concentration, high-pressure sprays are adapted for tall, dense vegetation and woody plants. Enough solution should be applied to wet the leaves. The dosage is adjusted by using enough 2,4-D to give the 2,4-D acid equivalent necessary for the dosage required. Dosage adjustments may be made with low-volume, low-pressure equipment by changing the nozzle size, nozzle spacing, pressure, or traveling rate of the equipment. Useful formulas for obtaining the volume output are given in "Calculating Dosages on a per Acre Basis," in Chapter 28.

The generally recommended dosages of 2,4-D for various weed-control problems are given in Table 47. The rates are expressed in terms of the 2,4-D acid equivalent necessary to do the job. The actual amount of a commercial product required can be determined by dividing the 2,4-D acid equivalent content of the product into the amount of 2,4-D required per acre. Example: the amount of 40 per cent 2,4-D commercial product necessary to equal 1 pound of 2,4-D is 1 divided by 0.40 (or 2 1/2 pounds).

Equipment in which 2,4-D compounds have been contained should not be used for crop spraying unless it is carefully and thoroughly cleaned, since even traces of 2,4-D can injure susceptible plants (see "Care of Equipment," Chapter 28).

Environmental Factors in Relation to 2,4-D Effectiveness

SOIL MOSTURE. The amount of moisture in the soil preceding and just after 2,4-D applications has an important bearing on its effectiveness. Poor results are obtained when the soil is too dry for rapid, succulent growth of weeds. 2,4-D is less satisfactory in regions of low rainfall and under desiccating conditions.

AIR TEMPERATURE. Low temperatures (50-70° F.) retard the killing action of 2,4-D but usually do not affect the final results. Temperatures above 95° F. tend to produce poor results because the high temperatures increase evaporation and retard growth. In general, treatments made at temperatures of 50° to 95° F. give the same final result, although they may take much longer at the lower temperature range.

AIR HUMIDITY. High humidity favors rapid absorption of the 2,4-D salts into the plants, because the salts are maintained longer in solution on the foliage. Low humidity is therefore considered unfavorable.

AIR MOVEMENT. Strong breezes and winds are to be avoided in timing 2,4-D applications; such air currents produce rapid evaporation and present a damage hazard to susceptible crops or ornamentals when the chemical or its vapor drifts, especially when the ester forms are used.

MOISTURE. Rain falling within an hour after treatment with 2,4-D salts reduces the effectiveness of the treatment, because the chemical is washed off. The esters are not affected by rain even a few minutes after application. When the foliage is wet with dew, dilute spray solutions should not be used, since further dilution occurs, along with excessive runoff. Wet vegetation, however, is ideal for high-concentration, low-volume sprays.

TABLE 47

TIMING OF AND RATES OF APPLYING 2,4-D* FOR VARIOUS SITUATIONS FOR POST-EMERGENCE WEED CONTROL

Crop or Situation	Pounds of 2,4-D Acid per Acre		Best Time To Apply
	Annuals	Perennials	
Aquatic weeds (water hyacinths)	–	8 (in oil)	August to April
Asparagus†	1/2 to 1 1/4	–	When plants are 1 to 2 ft. high, in spring or after harvest
Corn‡	1/4 to 1/2	1/2 to 3/4	When sprouts are up to 4 in. high; when higher, avoid hitting foliage
Dormant nursery stock (evergreen and deciduous)†	2 to 5	2 to 5	November through March
Flax (for seed purposes only)‡	1/8 to 1/4	–	When plants are 2 to 6 in. high
Grass seed crops (perennial)	1/4 to 1/2	1/2 to 1 1/2	In spring at full tiller stage
Hayfields, meadows (grasses only)	1/4 to 1	3/4 to 1 1/2	In spring at full tiller stage
Lawns and turfs	—	1 to 1 1/2	One or more applications in early spring and early fall
Nursery conifers†	3/4 to 1 1/2	1 to 2	Bases of older plants only, in early spring and after new growth has hardened

Table 47 (continued)

Crop or Situation	Pounds of 2,4-D Acid per Acre		Best Time To Apply
	Annuals	Perennials	
Pastures or grazing areas without legumes	1/4 to 1	3/4 to 1 1/2	In early spring or later
Rice	1/2 to 1	1	When 5–7 weeks old and flooded
Sugar cane†	1 to 2	1 to 2	When cane is 1–2 ft. tall
Strawberries	1/4 to 1	–	During first year when weeds are small
Waste areas	1 to 2	2 to 4	Spring when annuals and perennials are still small
Wheat (spring), oats, barley	1/4 to 1/2	1/2 to 3/4	Full tiller stage
Wheat (winter)	1/4 to 1	1/4 to 1	Full tiller stage
Woody brush	See Table 48		

*Esters should be used at lower dosage levels only.
†Avoid hitting foliage of crop.
‡Use on resistant varieties only.

QUESTIONS FOR DISCUSSION

1. How does a selective herbicide function?
2. Why are grasses more resistant than broad-leaved weeds to most herbicides?
3. Give the factors that should be investigated before a selective herbicide is applied to a crop.
4. Why is low-pressure, low-volume spraying equipment desirable in weed control with 2, 4-D?
5. Why is 2, 4-D so outstanding as a selective weed killer?
6. Minute amounts of 2, 4-D may severely affect some species of plants. Can you offer an explanation for this?
7. Why are the ester formulations of 2, 4-D the most hazardous to use?
8. Why is it difficult to use the sodium salt of 2, 4-D with low-volume equipment?
9. If a 2, 4-D formulation contains 40 per cent equivalent weight of acid and 2 pounds of 2, 4-D acid per acre are required, how much of the commercial formulation must be applied per acre?
10. What determines whether 2, 4-D applications are advisable and practical?
11. Why is 2, 4-D most effective on weeds that are growing actively?
12. What conditions favor the effectiveness of 2, 4-D? Hinder it?
13. Give a number of situations where 2, 4-D may be used advantageously.
14. Why should the use of 2, 4-D in dust form be avoided?
15. How should one go about cleaning up an area of brushland to be used for a pasture?
16. If one applies a 1 per cent (by weight) 2, 4-D solution at the rate of 10 gallons per acre, what should be the rate of the same solution per 100 square feet? Per square rod?

Chapter 24

SELECTIVE HERBICIDES OTHER THAN 2,4-D

SODIUM CHLORIDE (Common Salt). The most promising selective herbicide for growing sugar beets, cannery beets, and table beets is common salt. Beets have a high tolerance for concentrated salt solution which effectively kills young ragweed, smartweed, wild mustard, and rough pigweed, and usually stunts other weeds. Both lambs-quarters and purslane are resistant to salt injury. The salt may cause a temporary wilting of the beets, but they recover in a day or so. In many cases actual stimulation of beet growth has been obtained by the salt applications even though weeds were no problem.

THE DINITRO HERBICIDES. The dinitro herbicides were some of the first really promising, highly selective chemicals for large-scale use on crops. They consist of dinitro-o-sec-butyl phenol (Dow General), dinitro-sec-amyl phenol (Sinox), and ammonium dinitro-o-sec-butyl phenol (Sinox W and Dow Selective). Sinox W and Dow Selective are generally used in selective weed control, whereas the other two are mainly general, non-selective weed killers. These compounds are not translocated in plants and should be applied as coarse sprays at low pressures.

The dinitros are sold in the form of slurries or liquids that are readily soluble in water. They are non-corrosive, poisonous, and breathing of the mist should be avoided. Their use as selective herbicides has been mainly confined to the control of annual weeds in crops sensitive to 2,4-D, such as flax, canning peas, field peas, alfalfa seedlings, and onions. They may also eliminate nimblewill spots in bluegrass lawns. To give temporary elimination of weeds or grassy growth on non-crop lands they may be mixed with oil or an oil emulsion and used as non-selective weed killers.

As with the other weed killers, dinitros most easily kill broad-leaved weeds in the seedling stage. To control old or resistant weeds the dinitros are often combined with an activator such as ammonium sulfate or sodium bisulfate for greater effectiveness. The dinitros are also valuable in pre-emergence weed control.

Temperatures below 50^0 F. and application before cold and dry weather are unfavorable for the action of the dinitros. Rain after 1 hour does not nullify the effectiveness of the dinitros. See Table 48 for specific uses and dosages.

COMPARISON OF DINITRO AND 2,4-D COMPOUNDS AS SELECTIVE SPRAYS. The dinitros are as effective as 2,4-D on most species of annual weeds in the seedling stages under hot, dry conditions, but 2,4-D has been shown to be more effective when the weeds are large and under cool, damp conditions. Some common annual weeds in grains are killed more readily by dinitro weed killers than by 2,4-D; but some perennial weeds are more effectively controlled in small grains by 2,4-D than by the dinitros. Dinitros are ordinarily safer on some crops than 2,4-D, which can be used on flax only in low dosages and cannot be used at all on peas and other legumes. Dinitros may cause a temporary burn of crop foliage, but 2,4-D injury results in a permanent stunting effect or malformed growth, especially if applied at heavy rates.

SELECTIVE OIL SPRAYS. Carrots and other members of the parsley family are tolerant to applications of light-weight oils high in aromatic content, and on that basis such oils are the most successful weed killers developed for the control of weeds in this family. The killing action is rapid; often within 10 minutes all weeds hit are wilting. Weeds in seedling celery beds before transplanting and in seedling conifer nurseries may also be controlled with selective oils (Table 48). Directional low-volume spraying with aromatic oils by means of special nozzles that confine the spray to the weeds at the bases of the plants has been successful on sugar cane and on young cotton plants while the stalks still have a waxy coat. This method may be found applicable to many other crops with oil-resistant stems, while the weeds are small.

Oils no heavier than kerosene are used in selective weed control to avoid chronic injury to crops. Dry-cleaning fluids of the Stoddard solvent type sold commercially under trade names are best, because they can be used on seedling carrots without injury and are less apt to leave an objectionable flavor in the carrots. The oils should be applied as low-pressure sprays to wet the weed foliage.

Any of the above oils or similar ones can be used for nonselective weed control or for pre-emergence weed control and have the advantage of destroying annual grasses as well as broad-leaved weeds in their germinating or seedling stages.

The oils are also valuable for increasing the penetration of 2,4-D and 2,4,5-T into the bark of woody weed plants.

CALCIUM CYANAMID. This compound in either granular form or dusting grade is effective on young annual weeds and grasses in asparagus beds. The material is best applied to wet weed foliage. One application of the granular form or two to three applications of the dusting grade are necessary. There is no injury to the asparagus plants as long as the material is applied only to the bases of the plants. Either hand or machine application is feasible. Calcium cyanamid may also be used as a pre-emergence dust on onions, providing the weeds have germinated and are wet.

POTASSIUM CYANATE (Aero Cyanate). This water-soluble salt has given promising results with young weeds in onions, crab-grass in lawns, and as a directional stem spray in corn, asparagus, and gladioli plantings. It has been found particularly effective for purslane, pigweeds, chickweed, and lambs-quarters. Grasses beyond the seedling stage tend to be resistant. This chemical kills only by contact and leaves no residue in the soil, since it decomposes almost immediately after application. This characteristic makes it useful in pre-emergence weed control. Inhaling the fumes should be avoided. Onions should be sprayed only when dry, when the weeds are very small, and at low pressures (20 to 40 pounds per square inch).

2,4,5-T (2,4,5-Trichlorophenoxyacetic acid). This compound, closely related to 2,4-D, in its ester form and in combination with 2,4-D esters, shows promise in the control of many weed species, particularly the woody ones, that are resistant to 2,4-D. The isopropyl ester of 2,4,5-T in fuel oils or as an emulsifiable form in water, has been found especially useful against the brambles, poison ivy, osage orange, ground cherries, cottonwoods, oaks, and cat-tails. Plant responses are similar to those produced by 2,4-D, but the compound tends to be more injurious to plants than 2,4-D. It is also effective on brush stems or stumps during winter, alone or in combination with the isopropyl ester of 2,4-D in a fuel oil base.

PMA (Phenylmercuric Acetate). The chemical method of selective crab-grass control on lawns and turfs with PMA (PMAS) is a recent outstanding discovery. PMA is prepared under trade names as a concentrated liquid for dilution with water according to the manufacturer's directions. The diluted solution is best applied as a course spray with a sprayer at the rate of about 1 gallon per 75 square feet or 600 gallons per acre. This large volume is necessary to soak the soil, because the material is absorbed by the crab-grass roots and works up to kill the whole plant.

Crab-grass control with PMA can be obtained on bluegrass, fescue, clover, bent grass, and Bermuda grass lawns and turfs. Treatments cause temporary browning of lower grass sheaths and lightening in color of the blades. Grass growth is also temporarily retarded, but recovery is rapid.

Timing and Number of Applications. Applications may be made any time during the growing season, but best results are obtained when crab-grass is in the seedling stage. From two to five applications at 5- to 7-day intervals are necessary, depending on the stage of growth of the crab-grass and on the weather. More treatments and shorter intervals are required during cool weather or on more mature branched crab-grass. Applications work best when the weather is warm and when the soil is relatively dry. In dry, hot weather, watering the lawn 24 hours after an application increases the speed of kill.

This chemical is also effective in the control of the turf diseases known as brown patch, dollar spot, and copper spot. It can be used with certain 2,4-D formulations for nearly complete lawn-weed control. Like other mercury compounds, PMA is poisonous and should be handled and used with caution.

IRON SULFATE (Ferrous Sulfate). This green, crystalline salt has been generally replaced as a selective contact weed killer on grains by the dinitro and 2,4-D compounds, because of poor weed control and the necessity of damp, wet conditions following application. It is now used chiefly on cranberry bogs.

COPPER SULFATE. This blue, crystalline salt has also been replaced as a selective contact weed killer on grains, because of crop injury, cost of the chemical, and corrosiveness to equipment. This chemical is useful on cranberry bogs (Table 48).

PARADICHLOROBENZENE. This compound in the form of white crystals has been used on cranberry bogs for the control of weeds such as poison ivy, chokeberry, white violets, loosestrife, wild bean, and brambles.

SODIUM PENTACHLOROPHENATE AND PENTACHLOROPHENOL. The sodium salt of pentachlorophenol is partially selective and may be applied on non-susceptible crops, either in water solution or oil in water emulsion, before weed seedlings emerge but either before or after the crop plants emerge. It has been effective as a directional stem spray for weed control in sugar cane and pineapples in Hawaii and may also be adapted in a similar manner in the cotton and corn belts of the United States. It shows promise as a pre-emergence spray, with or without oil, for crops such as potatoes, corn sugar beets, legumes, and cucurbits. Oil formulations are best for emerged weed seedlings.

The acid, pentachlorophenol, must be dissolved in oils. It is still in the experimental stage but has shown promise in fortifying oils for pre-emergence crop treatments on sprouted weeds.

ISOPROPYL n-PHENYLCARBAMATE. There are some indications that this chemical, which has shown some selective effects on grasses and on some broad-leaved weeds, can be applied to strawberry plantings in the fall to kill chickweed. Ten to fifteen pounds of IPC per acre diluted with talc so that it could be dusted evenly over the strawberry rows killed nearly all of the chickweed by spring with no apparent reduction in yields.

TABLE 48

RATES OF APPLYING AND TIMING OF SELECTIVE SPRAYS OTHER THAN 2,4-D ON CERTAIN CROPS

Crop	Material	Acre Rate		Timing
		Chemical	Water	
Seed or fiber flax	Dinitros	Mfr's directions	70–100 gal.	When flax is 4–6″ tall
Carrots, parsnips, dill	Oils (Stoddard solvent type)	60–80 gal.	None	When carrots have 2–4 true leaves and later when necessary
Cannery peas	Dinitros	Mfr's directions	70–100 gal.	When peas are 4–8″ tall
	Cyanamid dust	70–100 lb.	None	Weed seedlings
Onions, garlic*	Dinitros	Mfr's directions	70–100 gal.	2-leaf stage to 10″ tall
	Potassium cyanate	6 lb.	70–75 gal. (1% solution)	When less than 6″ high but after crook stage
	Potassium cyanate	12 lb.	70–75 gal. (2% solution)	When taller than 6″

Table 48 (continued)

Crop	Material	Acre Rate		Timing
		Chemical	Water	
Asparagus*	Dinitros	Mfr's directions	70–100 gal.	When 2–3′ high
	Cyanamid dust	70–75 lb.	None	2–3′ high, but when weeds are wet
	Granular cyanamid	400–800 lb.	None	After disking, before cutting season
Strawberries	Isopropyl *n*-phenylcarbamate	15 lb. diluted with talc for dusting	None	In fall, for chickweed only
Pineapples*	Sodium pentachlorophenate	10–30 lb.	Enough for uniform coverage	Right after planting and later
Cannery beets	Sodium chloride (common salt)	200 lb.	100 gal.	When 4 true leaves are present
Sugar beets	Sodium chloride (common salt)	200 lb.	100 gal.	When 4 true leaves are present
Celery (in seedbeds)	Stoddard solvent	40 gal.	None	In seedling stages before transplanting

Table 48 (continued)

Crop	Material	Acre Rate		Timing
		Chemical	Water	
Gladioli*	Aero cyanate (potassium cyanate)	12 lb.	75 gal. (2% solution)	After glads are up but weeds are small
	PMA+2,4-D	4 lb. +1 lb.	75 gal.	After glads are up but weeds are small
Lawns, turfs	PMA	5.4 lb. of 6% solution	600 gal.	When crab-grass is in seedling stages
	Potassium cyanate	8–16 lb.	200 gal.	2–3 applications at weekly intervals when crab-grass is starting or before
Pastures and fields (for brush)	2,4,5-T+ 2,4-D esters	2 lb. of each (acid equivalent)	100 gal. fuel oil or water†	On bark and foliage or on freshly cut stumps, summer or winter

Table 48 (continued)

Crop	Material	Acre Rate		Timing
		Chemical	Water	
Cranberry bogs*	Iron sulfate (ferrous sulfate)	20–40 lb. per sq. rod	None	Under damp conditions during growing season
	Copper sulfate	20% solution (by wt.)	None	Early August for nut-grasses
	Paradichlorobenzene	7 1/2–10 lb. per sq. rod and covered with 1–2 in. of sand	None	Late spring; do not flood for at least 2 weeks after treatment
Ponds and pools	Copper sulfate	4 lb. per acre foot depth of water	None	Whenever green scum appears
Conifer nurseries	Oils (aromatic)	20–75 gal.	None	When seed coats are on coniferous seedlings; later on hardened growth during cool days

Table 48 (continued)

Crop	Material	Acre Rate		Timing
		Chemical	Water	
Sugar cane*	Sodium pentachlorophenate	10 – 30 lb.	Enough for uniform coverage	After planting and later

*Avoid hitting foliage–use directional nozzles.
†Water dilution more effective on foliage of brush.

QUESTIONS FOR DISCUSSION

1. What are the advantages and disadvantages of weeding beets mechanically as compared to weeding them by means of concentrated salt applications?

2. Why are the dinitro herbicides more effective on annuals than on perennials?

3. What advantages have the dinitros over the 2, 4-D compounds? Vice versa?

4. Why has the weeding of carrots by means of oils been adopted so readily by growers?

5. Why is weed control in an asparagus bed a problem?

6. On what basis should one select the chemical to be used in onion weed control?

7. A number of chemicals such as sodium chlorate, Ammate, 2, 4-D, and 2, 4, 5-T may be used in the control of woody weeds. On what basis should one or a combination of them be selected?

8. How is PMA used in crabgrass control?

9. PMA and 2, 4-D combined are a very useful on lawns. Why?

10. What are the advantages of using cyanamide on asparagus beds?

11. What advantages has a combination of 2, 4, 5-T and 2, 4-D esters on woody weeds?

12. Where are iron sulfate, copper sulfate, and paradichlorobenzene used as weed killers? Why are they not used more on other crops?

13. Do you think the future use of selective herbicides on a large scale may lead to complications from the standpoint of plant health? Human health?

14. What weed killer would be most suitable for a driveway? A railroad embankment? A children's playground? A field overgrown with brush? A hillside pasture? A tennis court?

15. A water solution of 2, 4, 5-T is more effective than an oil solution on brush in the summer, but an oil solution is more effective in the winter. Explain why this is so.

Chapter 25

PRE-PLANTING AND PRE-EMERGENCE WEED CONTROL

Most weeds when germinating or as tiny seedlings are easily killed by chemicals such as 2,4-D, Stoddard solvent, and the dinitros. This fact has led to the development of two methods for treating soil to kill weeds: (1) pre-planting; and (2) pre-emergence treatments.

PRE-PLANTING WEED CONTROL

Pre-planting weed control may be useful where crops are too sensitive to the chemical to permit pre-emergence spraying. In pre-planting treatments the soil is prepared for the crops, and the weed seeds are given time to germinate; then the chemical is applied, and the crop is planted as soon thereafter as is judged safe. This type of weed control, however, destroys only those weeds at the level at which germination usually occurs. Weed seeds below this level are not affected by chemicals currently in use. Planting devices that disturb the soil as little as possible should be used, since the new weed seeds brought up will germinate along with the crop. Pre-planting treatments may be made with any of the chemicals that decompose or evaporate readily, leaving no toxic residues.

PRE-EMERGENCE TREATMENTS

Pre-emergence treatments are those that are applied after the crop is planted but before the seedlings have broken through the ground. This method cannot be used on any crop sensitive to the chemical used; but it offers a very promising method of weed control on non-sensitive crops, because mechanical weeding is eliminated for 2 to 4 weeks or more at a time when the crop is most easily affected by weed competition. Two procedures are recognized: (1) contact pre-emergence and (2) residual pre-emergence.

CONTACT PRE-EMERGENCE. In contact pre-emergence a chemical is used to kill the tiny weed seedlings that emerge ahead of the crop. It is usually done a few days before the crop breaks through the ground, in order to allow as many weeds as possible to come up. The dosage should be light but thorough, so that no dangerous residues are left. This method is particularly adapted to slow-germinating, large-seeded, non-sensitive crops that can be planted deep enough to escape root and seed contact with the chemical. The success of the treatment depends on the proportion of weed seeds that have germinated at the time of application. The longer one can wait after the seedbed is prepared or before the chemical is applied the better the results will be. In general, the best procedure is (1) prepare the seedbed 7 to 10 days before planting; (2) plant the seed, disturbing the soil as little as possible; and (3) spray the weed seedlings at least 2 to 4 days before the crop comes up. Contact weed killers such as the light aromatic oils, certain dinitro compounds, and potassium cyanate have been used in contact pre-emergence treatments. Flaming by means of flame guns may also be effective on weed seedlings in contact pre-emergence treatments on many crops sensitive to chemical treatments.

RESIDUAL PRE-EMERGENCE. In this method, also referred to as selective soil sterilization, chemicals are applied to the soil at the time of, or a day or two after planting, to kill germinating weed seeds before they come up. The chemicals generally have a residual effect and may remain active in the soil for varying lengths of time, even long after the crop has emerged. This makes it necessary for the chemicals to have some selective action on the plant parts involved, otherwise injury will result. It is better than contact pre-emergence for crops that will tolerate a residual application of the weed killer, since weeds will be controlled over a much longer period. This method is also best suited to large-seeded crops and those propagated by bulbs, corms, and tubers. Tiny seeds that require shallow seeding are usually harmed by these treatments, especially in sandy soils.

Chemicals such as sodium pentachlorophenate, pentachlorophenol in oil, 2,4-D, and the ammonium salt of dinitro-o-sec-butyl phenol have given promising results in residual pre-emergence treatments. Formulations of 2,4-D are particularly adapted for non-sensitive or deep-planted crops such as corn, asparagus, sugar cane, potatoes, and gladiolus. Best results with 2,4-D and with the phenolic compounds are obtained when the weed seeds have been given time to start germinating. Combined contact and residual pre-emergence treatments may be effective on some slow-germinating crops by fortifying the light aromatic oils with any of the above residual compounds.

Residual pre-emergence treatments are safest on soils that allow little leaching, such as clay or loam soils, or soils high in organic matter. They are less safe on sandy soils where rapid leaching occurs and do not work at all on cloddy or stony soil. Heavy rains right after application of chemicals may carry them deep into the soil and cause crop injury. Crops should be irrigated before spraying. Many of the treatments listed in Table 49 should still be considered experimental and may be injurious to crops under certain soil or climatic conditions. Local experiment stations should be consulted.

Advantages of Pre-emergence Treatments

Pre-emergence treatment on certain crops offers the following advantages:

1. Controls seedling grass weeds nearly as well as broad-leaved weeds.
2. Costs less than hand weeding ($2 to $15 per acre).
3. Eliminates much labor.
4. Eliminates early weed competition, producing better stands and more vigorous plants.
5. Reduces the number of cultivations so that fewer weed seeds are brought to the surface.
6. Prevents rapid-growing weeds from outgrowing plants and from reaching a stage when they are difficult to eradicate, even if selective sprays can be used.
7. May eliminate all cultivation on certain crops if selective post-emergence sprays can also be used safely.

TABLE 49

PRE-EMERGENCE TREATMENTS FOR WEED CONTROL ON CERTAIN CROPS

Crop	Material	Acre Rate		Timing
		Chemical	Water	
Asparagus	2,4-D	2–3 lb.	10 gal.	1 week after disking, before or or after the cutting season
	Potassium cyanate	12 lb.	75 gal. (2% solution)	1 week after disking, before or or after cutting season
	Sodium pentachlorophenate	20 lb.	75 gal.	In spring, after disking but before crop emerges
Beans, Lima beans	Aromatic oils	Mfr's directions	None	1 or 2 days before beans break through soil
	Sodium pentachlorophenate	30 lb.	75 gal.	At seeding
Melons, squash	Sodium pentachlorophenate	20 lb.	75 gal.	At seeding
Corn	2,4-D	3/4–1 1/2 lb.	10 gal.	Just as sprouting tips appear or before
	Calcium cyanamid	400 lb.	None	Week after planting
	Sodium pentachlorophenate	Mfr's directions	None	At seeding or 1 day later

Table 49 (continued)

Crop	Material	Acre Rate		Timing
		Chemical	Water	
Onions	Potassium cyanate	12 lb.	75 gal. (2% solution)	2 to 4 days before emergence
	Calcium cyanamid (dust)	70–75 lb.	None	Right after seeding to within 2 days of emergence, but week after seedbed is in preparation
Beets	Aromatic oils	Mfr's directions	None	On weed seedlings 2 to 4 days before crop emerges
	Dinitros	Mfr's directions	None	On weed seedlings 2 to 4 days before crop emerges
	Potassium cyanate	12 lb.	75 gal.	On weed seedlings 2 to 4 days before crop emerges
Potatoes	2,4-D	1 1/2–2 lb.	20 gal.	2 weeks after planting
	Sodium pentachlorophenate	10 lb. +10 gal. diesel oil+ emulsifier	90 gal.	2–4 days before emergence
Cotton	Sodium pentachlorophenate	20 lb.	75 gal.	At seeding
	Dinitros	Mfr's directions	None	2 days after planting

Table 49 (continued)

Crop	Material	Acre Rate		Timing
		Chemical	Water	
Sugar cane	Sodium pentachlorophenate	20–30 lb.	75 gal.	Right after planting
	Pentachlorophenol	5–10 gal., 10% emulsifiable oil solution	Enough for uniform coverage	Right after planting
Gladioli	2,4-D	2–3 lb.	10 gal.	2 weeks after planting
	Sodium pentachlorophenate	20 lb.	75 gal.	1 or 2 days after planting
	Sodium pentachlorophenate+ 5% fuel oil+ emulsifier	20 lb.	75 gal.	2 weeks after planting

QUESTIONS FOR DISCUSSION

1. What is meant by pre-planting chemical treatments?
2. Under what conditions are pre-planting treatments useful? Pre-emergence treatments?
3. Why is cultivation bad after pre-planting or pre-emergence treatments?
4. What effect does soil type have on the success of pre-emergence treatments?
5. What procedure should be followed in pre-emergence treatments? Present reasons for each step.
6. Why are 2, 4-D compounds preferred to other chemicals where they can be used in pre-emergence treatments?
7. Present some advantages of pre-planting and pre-emergence treatments over post-emergence treatments.
8. Why are slow-germinating crops better adapted for pre-emergence weed control?
9. What determines the safe interval between chemical pre-planting treatments and the planting of a crop?
10. What is meant by contact pre-emergence treatments? Residual pre-emergence treatments?
11. What factors should determine the choice of a herbicide for various situations?

Chapter 26

APPLICATION EQUIPMENT I

No matter how skillful and experienced an operator is he cannot do a better job of applying pest-control chemicals than the efficiency of the application equipment will let him. Conversely, a poor operator may get discouraging results even with the best equipment. The ideal requirement for equipment for chemical applications is to make possible an even, thorough coverage of the plants or crops at the right time with the minimum of time, labor, and materials.

The application of chemicals for pest control is one of the most disagreeable chores of the average grower. It has undergone great changes from the days of the crude broom or brush for slopping on the materials. In fact, the changes that have taken place threaten to make the standard spray gun obsolete for large-scale operations, since these changes tend to eliminate labor and increase the speed of application without sacrificing evenness and thoroughness of coverage. Depending on their nature, pest-control chemicals may be applied from sprayers, dusters, mist sprayers, sprayer-dusters, or aerosol or fog applicators. The equipment may be carried, wheel-borne, tractor-borne, truck-borne, or air-borne.

SPRAYING EQUIPMENT

The purpose of spraying equipment is to eject chemical solutions, suspensions, or emulsions in the form of finely divided droplets so that they may be deposited evenly on the plants or pests. A sprayer consists of definite parts, each with a definite function. Since most sprayers are built on similar principles, an understanding of how one operates will make it easy to understand how all function.

The Parts of a Sprayer and Their Function

The parts common to most large sprayers are the tank to hold the spray, the pump to take up and discharge the liquid under pressure, the spray gun or nozzle to break up the liquid into the desired spray, and the engine to operate the mechanism (Fig. 192).

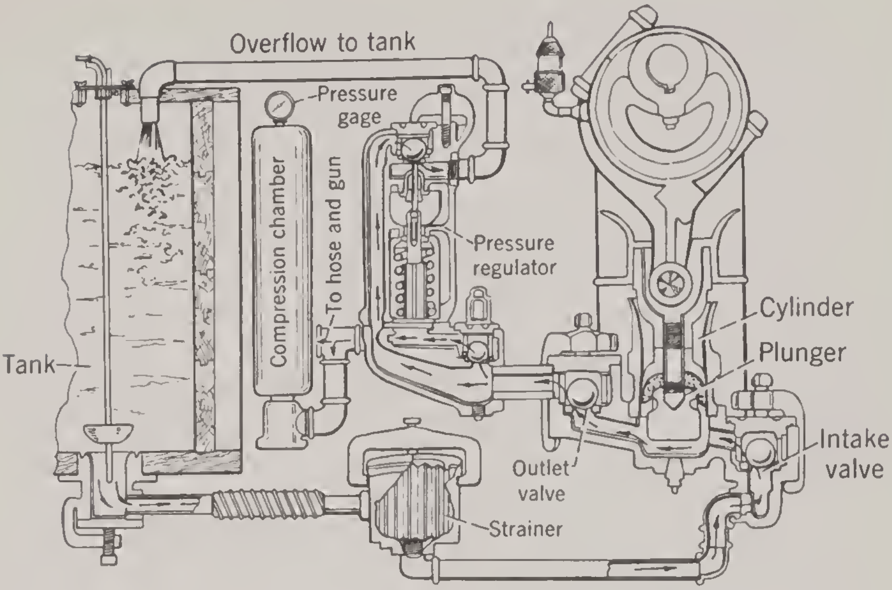


FIG. 192. Parts of a typical spray pump indicating courses of spray.

THE TANK. This may be made of wood or steel. Tanks vary in capacity from a few to 500 gallons, depending on the pump capacity and the purpose for which the sprayer is to be used. Steel tanks are generally painted on the inside with a corrosion-resistant paint. The tank should contain a good agitator to keep materials in suspension and to prevent uneven spray strengths. The tank should also be equipped with a strainer through which the materials are strained; and a strainer in the intake pipe leading to the pump, because hard particles are an important source of spray-pump trouble and nozzle clogging.

THE SPRAY PUMP (Fig. 192). This consists of one to four cylinders in which the spray pressure is developed, and corresponding plungers or pistons that create the spray pressure by sucking the spray into the cylinders through intake valves and forcing it out under pressure through outlet valves. The plungers are made to fit tightly within the cylinders, usually by means of packing or leather cups that can be tightened or replaced as the need arises. The number of cylinders and their diameter have a direct bearing on the capacity of the pump. Engine-driven pumps have capacities from 1 to 2 gallons per minute to more than 60 gallons per minute, depending on the pressure and on the number of cylinders and their diameter. The pump capacity in turn determines how many nozzles of a certain size may be used and still maintain the desired pressure.

THE VALVES (Fig. 193). These are usually of the ball-and-seat type, are made of bronze or stainless steel, and work on the principle of allowing flow of liquids in one direction only. Thus each pump cylinder must have two ball valves—one to allow the spray to come in and the other to let the spray go out. The valves are one of the chief sources of trouble in spray machines and should be easy to reach for cleaning. The following valve troubles may cause loss of pressure or loss of spray volume:

1. Spray or dirt particles may wedge on the seat and prevent the ball from fitting snugly on it.
2. The balls may grow sticky from the spray materials and become stuck on the seats if the machine is put away without a thorough cleaning.
3. The seat or ball may become scratched or dented by hard particles and may allow a backward flow.
4. The ball or seat may become corroded or worn through long use and thus not function properly.

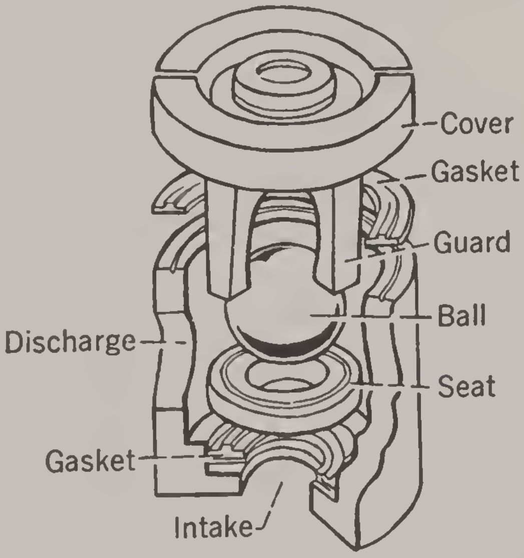


FIG. 193. A ball and seat valve.

COMPRESSION PARTS. From the cylinders the spray material passes to a T-joint, one end of which leads to an air or compression chamber. Where pressure is built up by air compression to produce a cushioning effect and to prevent sudden drops in pressure or a pulsating spray. In one-cylinder pumps, it makes possible an even, continuous flow of spray even between strokes of the piston. If an air chamber is missing, as it may be on some small, hand-operated sprayers, a spray is produced only at each downward stroke of the piston.

The other end of the T-joint leads to a pressure regulator (Fig. 194). The pressure regulator is used for adjusting the pressure to the desired height and in addition functions as a safety valve, preventing excess pressure from being built up, especially when the guns are shut off. When the spray material enters through the intake ball valve, it presses up on the spring diaphragm, down on the relief ball valve, and passes out to the hose and spray gun. When the liquid pressure exceeds that for which the spring was set, the spring is forced to contract. In so doing, it pushes up a pin that in turn moves the relief ball valve off the seat. This allows the excess pressure in the form of spray to pass the valve and flow back into the tank. Even when the spray guns are opened fully there should be some spray flowing back into the tank, since the pump output should always be greater than the spray gun or nozzle capacity. For most spray work, pressures from 300 to 600 pounds per square inch are common. Small, garden-type engine sprayers are usually run at 150 to 200 pounds pressure and weed sprayers at 30 to 60 pounds pressure.

A pressure gage is generally placed somewhere in the line, beyond the spray pump. It may be on the air chamber or near the point of attachment of the spray hose, so that the operator can see that the desired pressure is being maintained.

The hose on sprayers is built to withstand high pressures and varies in length according to the needs of the operator or the spraying conditions. The standard length on orchard sprayers is 50 feet. Each hose on a sprayer leads to a spray gun or a spray boom, depending on the type of crop for which the sprayer is adapted.

SPRAY GUNS. A spray gun consists of a long or short barrel made of light metal, one end of which is attached to the hose and has a shutoff valve, the other end of which has a

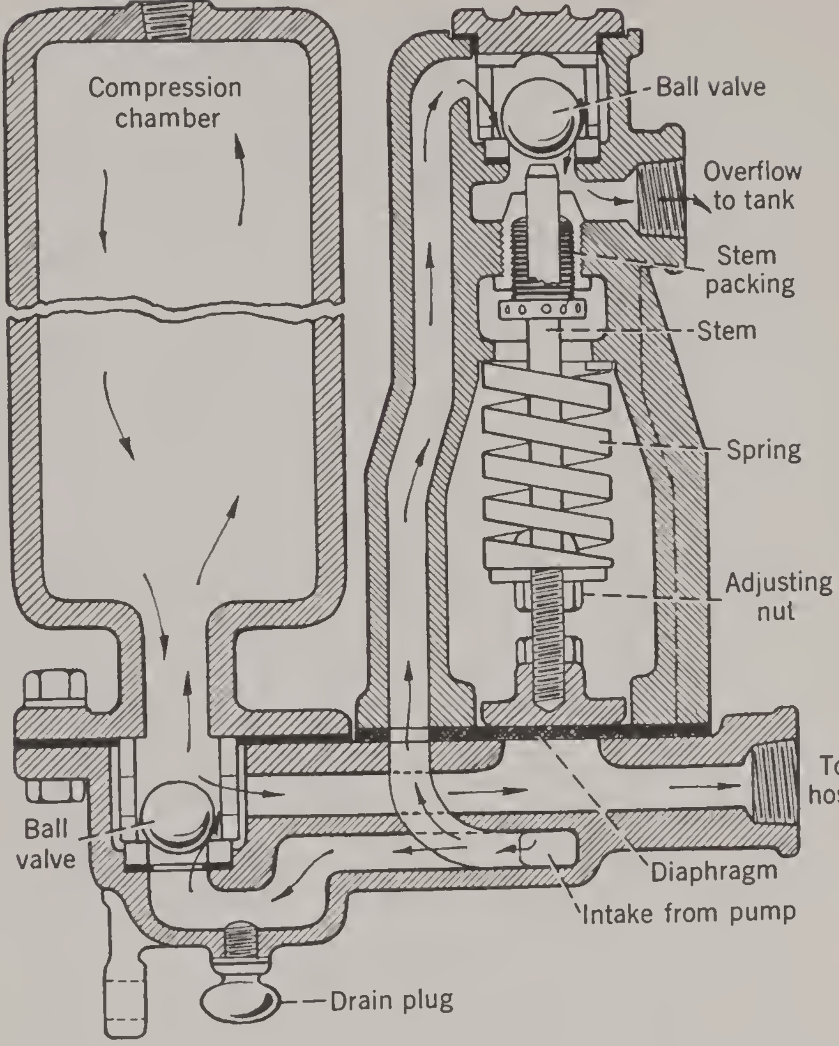


FIG. 194. The course of the spray through a pressure regulator and compression chamber (courtesy of John Bean Mfg. Co.).

nozzle for producing the type of spray desired. The shutoff may be of the trigger type, as is usually found on small spray guns for hand-operated equipment; or it may be of the screw type most often found on spray guns used with power equipment.

The small-volume spray guns generally used with hand-operated equipment commonly have an adjustible nozzle and a trigger shutoff. All-purpose spray guns produce a short, misty spray to a long, coarse spray, depending on how far the shutoff valve is opened. This type of spray gun is useful where trees and shrubs of various heights have to be sprayed at the same time. The orchard or broom type of spray gun (Fig. 195A) may have anywhere from two to eight nozzles arranged on a crosspiece so as to throw a long, fairly flat spray. This type of gun allows for speed along with thorough coverage as long as the trees are not too high. The shade-tree gun (Fig. 195B) is usually provided with a long barrel and a rifle-like nozzle that throws a coarse spray to great heights, breaking up as it ascends. This type of gun is used in combination with high-pressure, high-output pumps to spray tall shade trees.

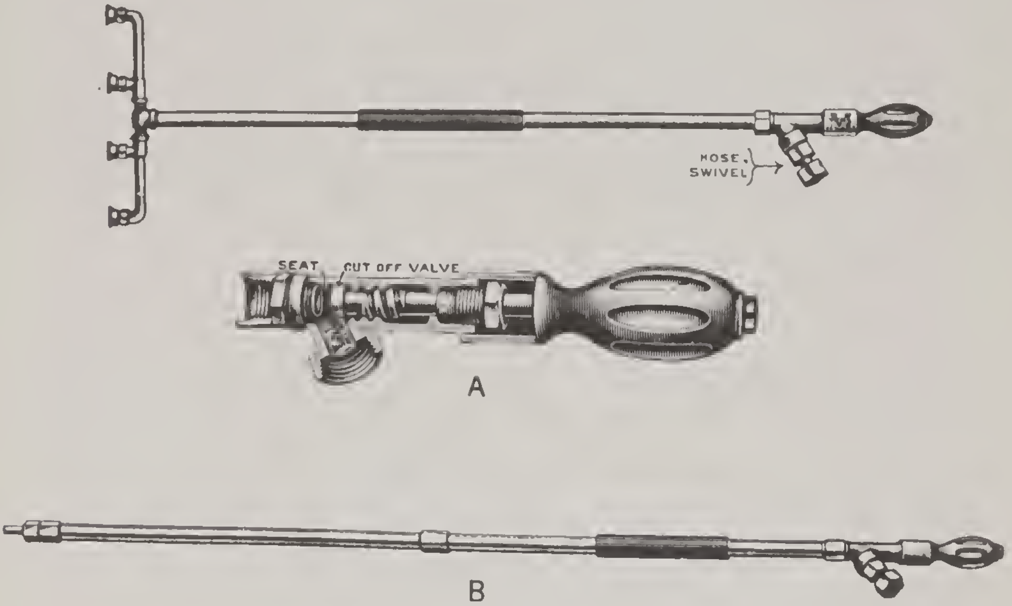


FIG. 195. A, broom type of spray gun showing screw-type cutoff valve; B, a shade-tree gun good for long-distance spraying (courtesy of F. E. Meyers and Bros. Co.).

SPRAY BOOMS. Spray booms are used for row crops and are of various designs, determined by the crops to be treated (Fig. 196). They may be made to take care of from one to sixteen or more rows at a time. For insect and disease control their nozzles should be so arranged as to spray the plants from all sides—usually three nozzles per row are used.

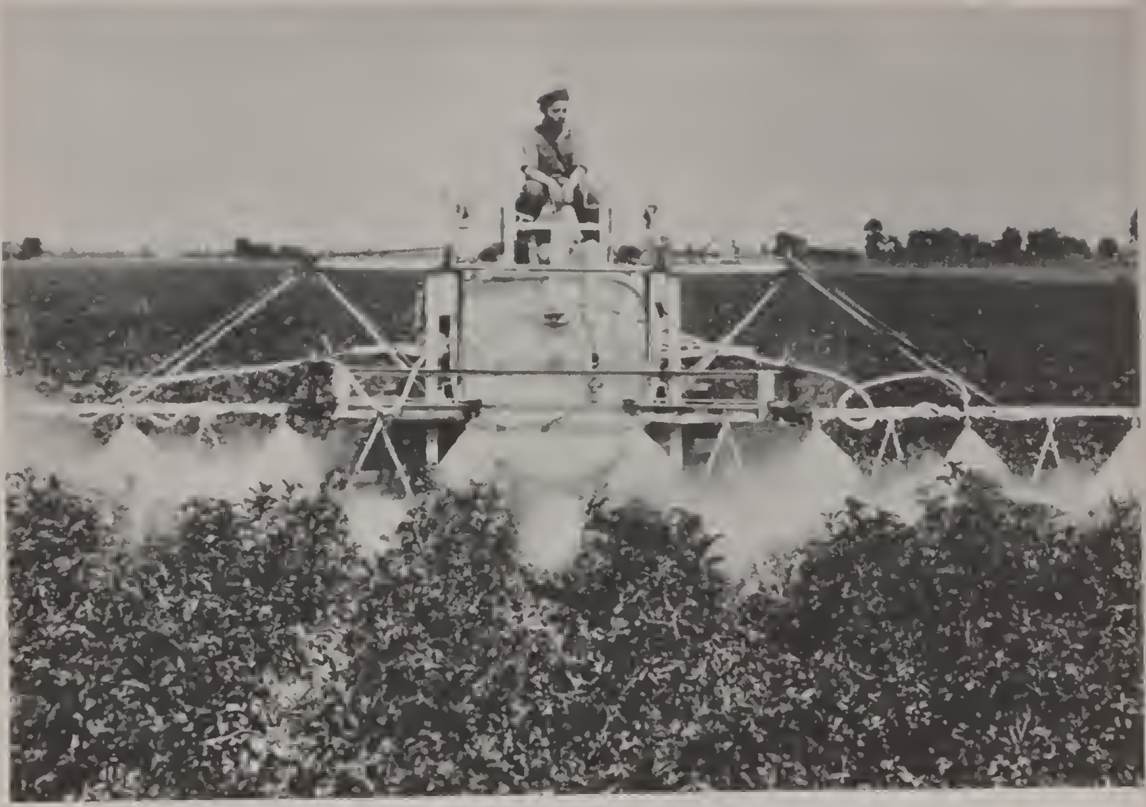


FIG. 196. An 8-row spray boom in action on a potato field (courtesy of F. E. Meyers and Bros. Co.).

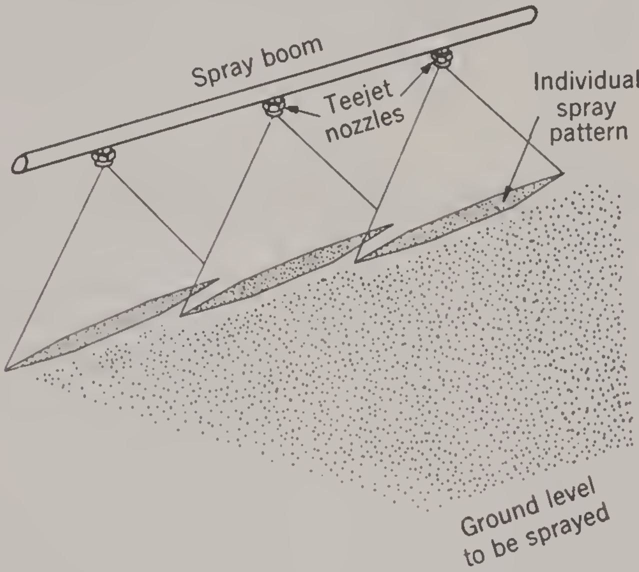


FIG. 197. Arrangement of nozzles on a spray boom for weed control (courtesy of Spraying Systems Co.).

Spray booms for weed control have nozzles arranged at intervals on the spray boom and at the right height above the ground so that the flat sprays from each nozzle slightly overlap each other (Fig. 197). Wide spray booms are made with hinged wings so that they can be folded out of the way of fences and other obstacles during spraying. Some sprayers put out by companies are equipped with spray masts for speedy orchard spraying (Fig. 198). Such spray masts may have rigidly fixed batteries of nozzles or adjustable ones, so that the operator can adjust them to each tree as the sprayer passes by. Some sprayers are equipped with spray towers for better and easier coverage of the tops of trees (Fig. 199).

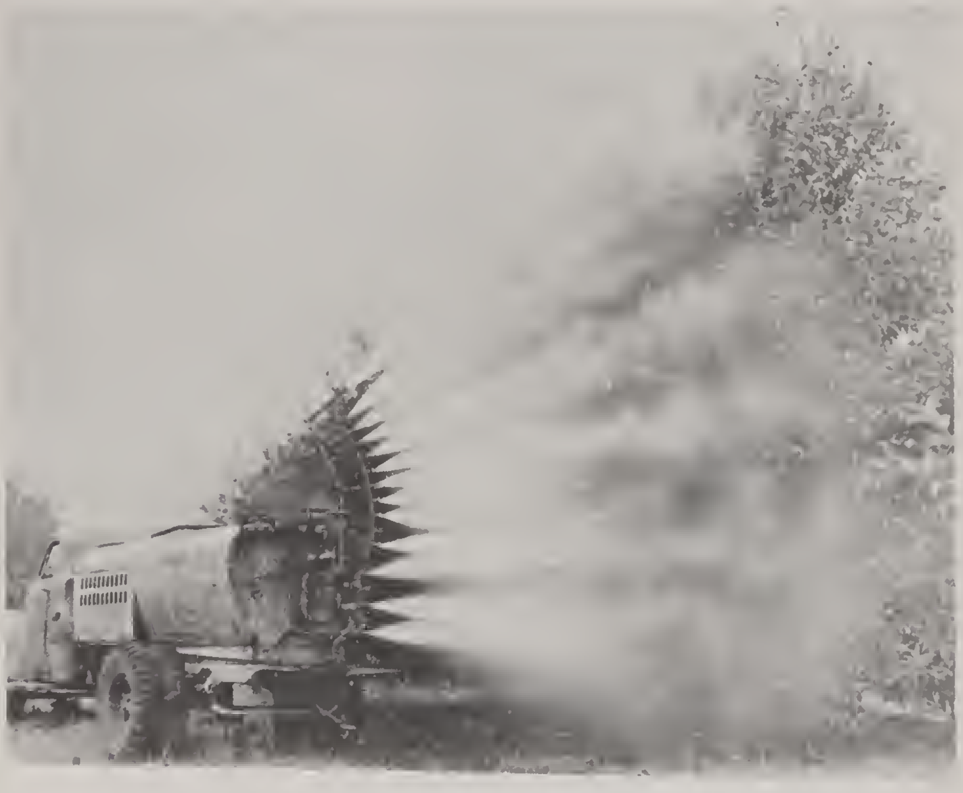


FIG. 198. A fixed type of spray mast for use in orchards (courtesy of Hardie Mfg. Co.).

SPRAY NOZZLE PARTS AND THEIR FUNCTION. The parts of a typical spray nozzle are shown in Fig. 200. They are the base, the screw cap, the disc, the washer, the vortex plate, and the strainer. In large spray guns the strainer may

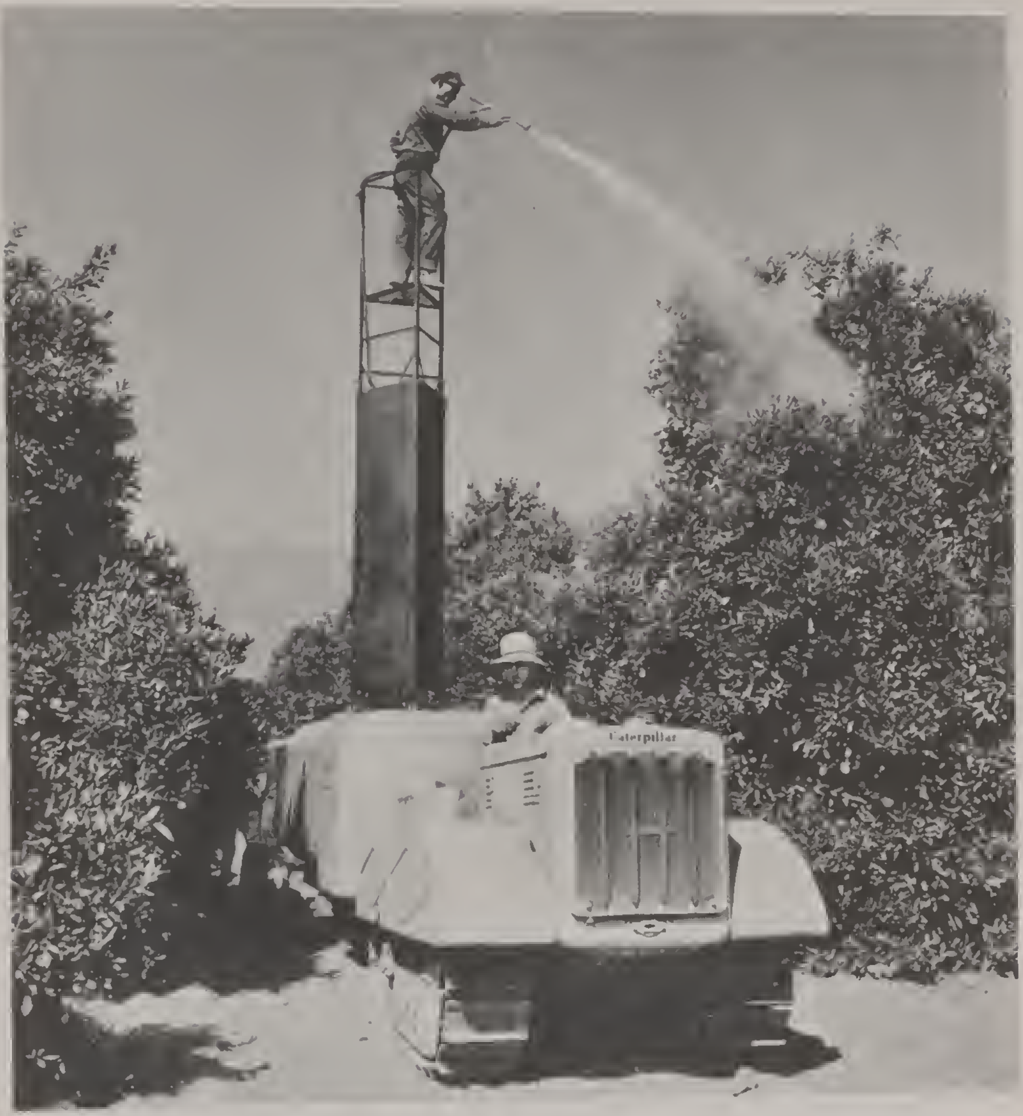


FIG. 199. A spray tower insures good coverage of the tops of trees (courtesy of Hardie Mfg. Co.).

be left out of the nozzle and the vortex plate may have more openings.

Clogging is the most frequent cause of trouble with nozzles, and anyone who uses them should be able to take them apart and put them together again correctly. The base of the nozzle and the screw cap hold all the parts in place. The disc is equipped with one hole in the middle and is usually numbered from two to ten. The number denotes the diameter of the orifice in sixty-fourths of an inch. The size of the orifice regulates the volume of spray and in hand-operated equipment indirectly affects the pressure that can be built up. Disc holes may enlarge or may become lopsided after much use, and the discs may need to be replaced. In nozzles producing a flat spray pattern the orifice is in the center of a long, longitudinal groove in the disc.

The washer under the disc prevents leakage and produces an eddy chamber, the depth of which in turn determines the angle of the spray cone in nozzles producing hollow-cone sprays. The vortex plate has near its outer edge two or more openings that slant through at an angle and throw the spray into a spin in the eddy chamber. This causes the spray to break up into the form of a hollow cone when it leaves the disc. The vortex plate is absent in nozzles producing flat spray patterns. The strainer helps prevent nozzle clogging.

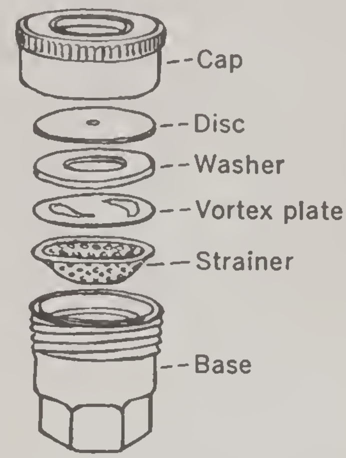


FIG. 200. The parts of a standard nozzle.

Hand-Operated Sprayers

ATOMIZER TYPE. These sprayers are made to hold from a pint to a gallon of spray and are most useful in and around the home where limited areas must occasionally be treated. This type of sprayer produces a fine mist and may be used with either solutions or suspensions. With suspensions, frequent shaking of the contents is necessary to prevent settling.

Advantages

1. Low priced and handy with small quantities of spray on limited areas.

Disadvantages

1. Limited to small jobs.
2. Not suitable for good coverage of low-growing crops.
3. Short carrying distance of spray.

COMPRESSED-AIR TYPE. These sprayers (Fig. 201) are made to hold from 2 to 4 gallons of spray and operate on air compressed in the tank by means of an air pump. These sprayers should not be filled more than three-quarters full of spray, since an air space is necessary to build up air compression. The sprayers are carried slung over the shoulder by means of a strap. They are usually equipped with a trigger shutoff type of spray gun operated by hand. They are useful in small gardens and where a few trees and shrubs of limited height are to be sprayed.

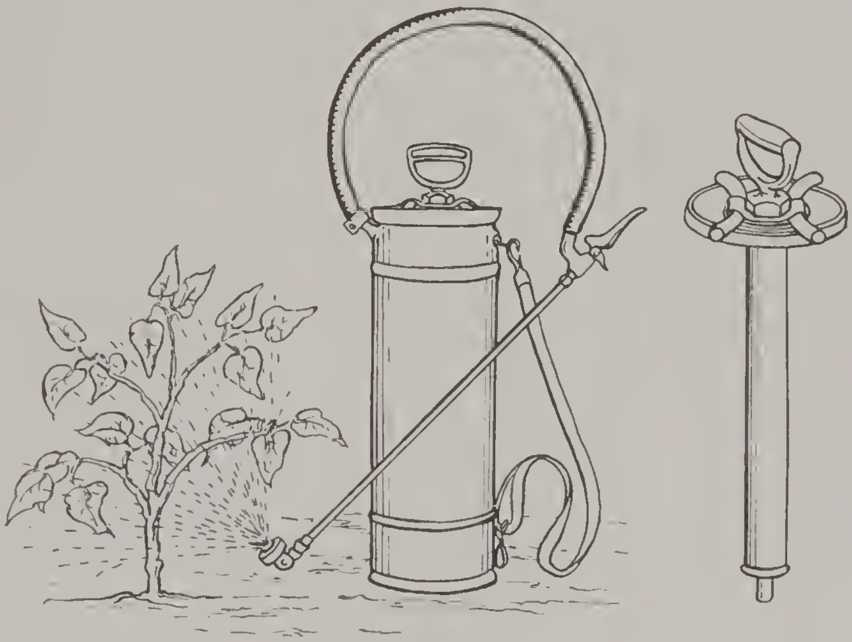


FIG. 201. A knapsack type of compressed-air sprayer.

Advantages

1. Low priced.
2. Simple to operate.

Disadvantages

1. Uncomfortable to carry and operate for any length of time.
2. Must be frequently shaken when suspensions are used.
3. Varying pressure—tank must be pumped up several times before it is emptied.
4. Limited carrying distance of spray.
5. Parts wear out quickly and corrode easily unless made of copper.

KNAPSACK SPRAYERS. These hold 2 to 5 gallons of spray and in general have the same uses as compressed-air sprayers. They are carried on the back like a knapsack, and the right hand operates a pump equipped with an air chamber to produce a continuous pressure. The left hand operates the spray gun.

Advantages

1. Uniform pressure may be maintained.
2. Equipped with an agitator.

Disadvantages

1. Tiring and uncomfortable to operate for any length of time; heavy load; pumping action produces bruises.
2. More expensive than compressed-air sprayers.

BUCKET PUMPS. These are small pumps (Fig. 202) that mav come equipped with or without a bucket that may vary in capacity from 2 to 4 gallons. They are generally equipped with an air chamber so as to produce a continuous spray pressure. Agitation is usually produced by a brass plate connected to the pump handle by a rod, or by a spray jet from the bottom of the pump. They are used for many of the same purposes as the other two types of sprayers. Two people are generally required to do a good job with this type of outfit: one to carry the bucket and pump, the other to do the spraying. At least 10 feet of hose are needed for increased maneuverability.

Advantages

1. Inexpensive.
2. Easy to operate and to maintain even, high pressure.
3. Greater carrying distance of spray.

Disadvantages

1. Pump and bucket with spray must be carried from place to place.
2. Equipment must be set down to pump.

3. Constant pumping required to maintain pressure.
4. Frequent refillings required for any amount of spraying.

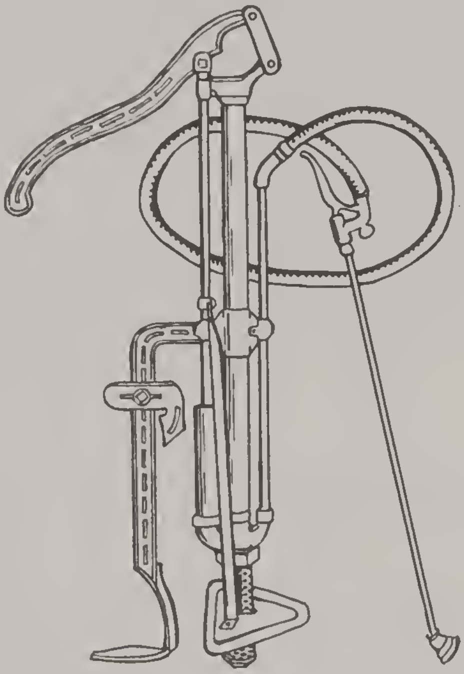


FIG. 202. A bucket pump.

WHEELBARROW AND BARREL SPRAYERS. These types of sprayers (Fig. 203) are equipped with 10- to 50-gallon tanks in which are placed pumps similar to bucket pumps but larger and more powerful, so that greater spray volume and pressures may be used. The whole outfit is usually mounted on a wheelbarrow frame or on a two- to four-wheeled frame for easy portability. A compression chamber is essential with these pumps to supply a continuous spray at an even pressure. These sprayers are made in a number of styles and designs and are adaptable for shrubs, small orchards, and fairly large vegetable gardens. Those for greenhouses are generally built quite narrow so as to fit easily in the walks between the benches.

Advantages

1. All the advantages of the bucket pump plus portability.
2. Higher pressures and spray volumes obtainable than with bucket pumps.

3. Greater spray-carrying capacity.
4. Can take care of greater areas than any of the previously mentioned types.

Disadvantages

1. Two men required for effective operation.
2. Pushing or pulling full tank hard work, especially on soft ground.
3. Limited to fairly level areas.
4. Ineffective use of manpower for the amount of work done.

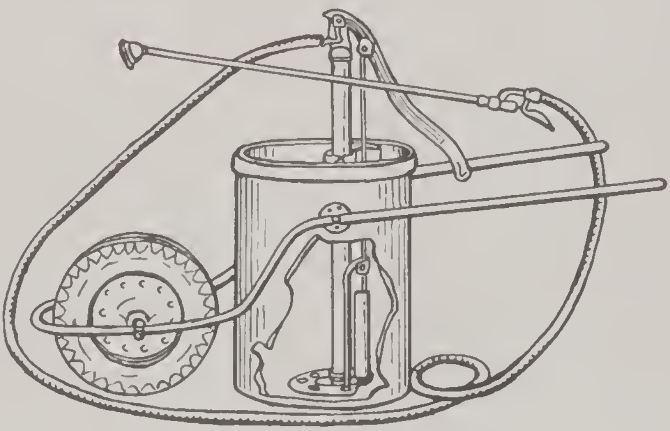


FIG. 203. A wheelbarrow sprayer.

TRACTION SPRAYERS. These sprayers get their power for operation through gears connected to the wheels. They may be either horse- or tractor-drawn, but since the wheels must be moving to maintain a constant pressure this type of sprayer is suitable only for row crops. The tank capacity varies from 50 to 200 gallons. The operator rides on the equipment.

Advantages

1. Less costly than power sprayers.
2. Cheaper to operate, since no engine is required to drive pump.

Disadvantages

1. Cannot build up as high pressures as engine-driven pumps.
2. Pressure variable, depending on speed.
3. Does not do as good a job as engine-driven pumps, especially near ends of rows.

4. Greater strain on horses or tractors.

Power Sprayers

Engine-operated sprayers vary from small, handy, wheelbarrow or two-wheel mounted sprayers with a 10- to 15-gallon tank capacity to huge 500-gallon sprayers mounted on four-wheel or truck chassis.

SMALL POWER SPRAYERS. These may be of the wheelbarrow type, barrel type, or estate type (Fig. 204). They vary greatly in construction and design, but essentially they all function in a similar manner. Those suitable for greenhouse spraying are generally equipped with electric motors. The chief defect of the one-wheeled wheelbarrow types is that they are easily upset and thus subject to damage. The two-wheeled types are more stable, but those with tank capacities of 25 to 50 gallons are difficult to push or pull around when they are full of spray. Some of these may have a tractor hitch and obviate the necessity of manpower for locomotion. These sprayers are usually equipped with one- or two-cylinder pumps

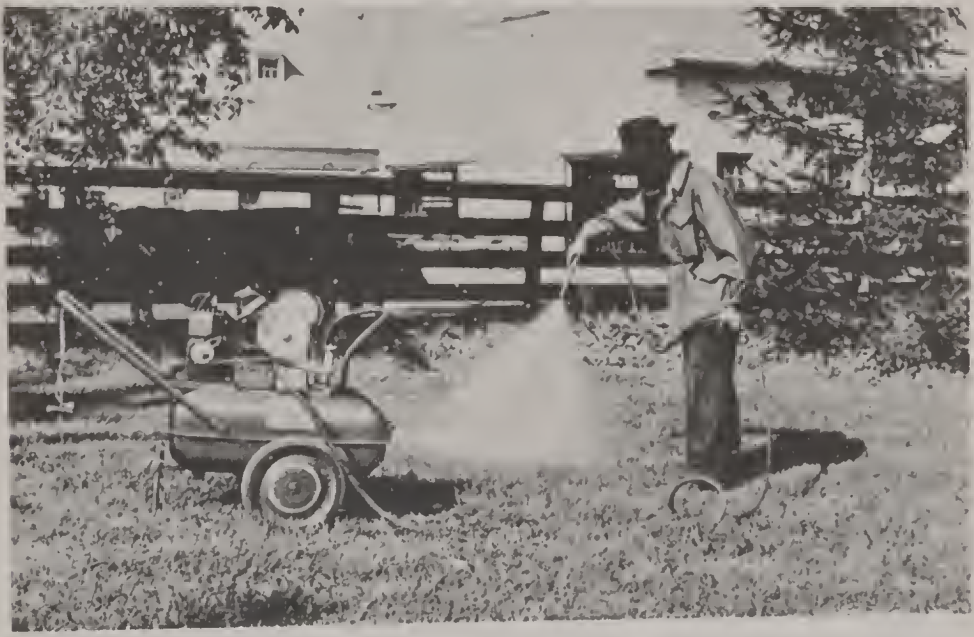


FIG. 204. A small 15-gallon power sprayer (courtesy of John Bean Mfg. Co.).

with capacities of 1 to 6 gallons per minute and with maximum pressure limited to 200 or 300 pounds. A good agitator is essential to keep materials in suspension. They are usually equipped with a hose and spray gun, but some may be adapted for row-crop spraying by attaching a spray boom. These sprayers are suitable for flower and vegetable gardens, greenhouses, shrubbery, and small orchards.

Advantages

1. Labor of pumping eliminated.
2. Can be operated effectively by one man.
3. Maintain high, even pressure.
4. Pumps have greater capacity than hand-operated ones.
5. Perform the job more quickly and efficiently.

Disadvantages

1. Much more expensive than hand-operated equipment.

SPRAYING ATTACHMENTS ON GARDEN TRACTORS. Many garden tractors either come equipped with detachable spraying attachments or may be equipped with them. These spraying attachments usually consist of a small one- or two-cylinder pump or air compressor, a spray tank, and a spray boom or hose and spray gun. The power takeoff for the pump or air compressor generally consists of a belt and pulley arrangement with the tractor's engine. For weed control, low-pressure, low-volume pumps are used with the power takeoff (Fig. 205); sometimes pressure is supplied by cylinders of dry ice (carbon dioxide) in combination with low-volume nozzles.

Spraying attachments on garden tractors generally perform as well as similar, unattached spray units and have the advantage of mechanical mobility. They have the same uses as separate engine-powered sprayers of similar pump and tank capacities.

Advantages

1. Engine can be used to operate attachments other than sprayers.
2. Cost of spraying attachments may be less than cost of similar spray units.
3. Motive power all mechanical.
4. Better adapted for row crop or ground spraying than man-pulled or -pushed equipment.
5. May be used in conjunction with other attachments such as cultivator or lawn-mower.

Disadvantages

1. Mounting and taking off spray equipment takes time and labor—equipment often must be taken off when tractor is used for purposes other than spraying.
2. Good spray agitation may be lacking.

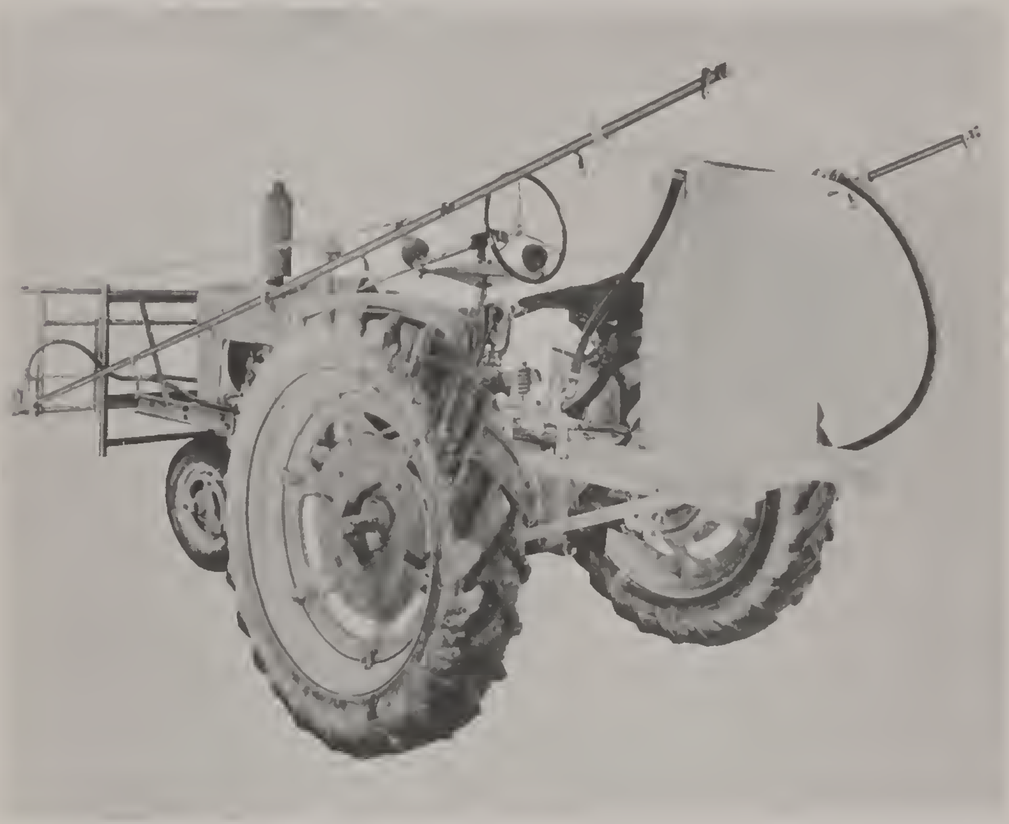


FIG. 205. A low-pressure, weed-spraying attachment mounted on a tractor (courtesy of A. B. Farquhar Co.).

LARGE POWER SPRAYERS. Large power sprayers may be of several types. Their tank capacities range from 100 to 500 gallons. They may be mounted on a four- or six-wheel chassis and have their own engines, or they may be of a trailer type mounted on two wheels with their own engines or with a tractor take-off to run the pump. The four- or six-wheel cut-under models are popular because the machine can be turned in its own length. The pump capacities vary from 12 to more than 60 gallons per minute, with engines of suitable horse-power to run them. Maximum spray pressures run from 400 to more than 800 pounds per square inch. They may be equipped with one or more 50-foot lengths of hose, with spray guns, with a spray boom for row-crop spraying, with spray masts, or with turrets of nozzles for rapid coverage of fruit trees. The tractor takeoff models eliminate the cost of an extra engine, but they require tractors of a certain design and horsepower to work effectively (Fig. 206).

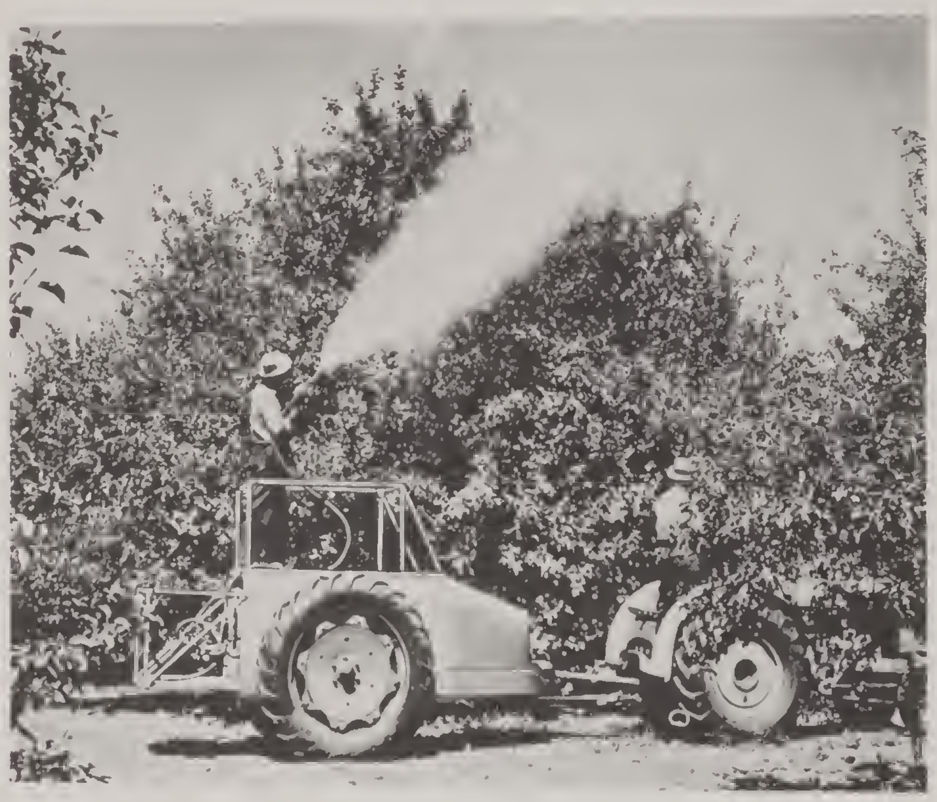


FIG. 206. A tractor-trailer sprayer in operation (courtesy of John Bean Mfg. Co.).

Advantages

1. Give good service over a period of years.
2. Cover large areas of row crops in good time (up to 35 acres per day).
3. Spray can be directed with accuracy.
4. Adaptable for many types of crops and for all insecticides and fungicides.

Disadvantages

1. Require large amounts of water—must have good source of water.

2. Equipment heavy, especially when tank is filled—may bog down in wet weather.
3. Require heavy tractor equipment for motive power.
4. Spray gun applications slow, hard, distasteful work as compared to use of spray masts or new speed application equipment.
5. Expensive in labor, material, equipment, and time when compared to latest equipment.

QUESTIONS FOR DISCUSSION

1. Why can application equipment be no more efficient than the man operating it?
2. What are the different ways in which chemicals may be applied for pest control?
3. Compare the advantages of steel tanks with wooden tanks on sprayers.
4. Why is a good agitator so important in a sprayer?
5. What are the effects of a clogged strainer in a sprayer?
6. Explain how a spray pump works.
7. What is the importance of a pressure regulator in a sprayer?
8. What happens when the nozzle output exceeds the pump capacity? Vice versa?
9. What are the possible causes of a drop in pressure or of insufficient pressure?
10. What may go wrong with ball valves in a spray pump?
11. Of what importance is a compression chamber?
12. Where are all the possible trouble points on a sprayer located?
13. Explain why an orchard type of spray gun is most effective for trees that are not too high.
14. What are the features of a desirable type of spray boom for row crops?
15. Under what conditions are spray masts effective for tree spraying?
16. What part of an apple tree normally has the most wormy apples or diseased foliage? Why?
17. What is the function of each of the parts of a spray nozzle?

18. What type of sprayer would be most suitable for a small home garden? A small fruit planting? A commercial fruit orchard?

19. Under what conditions are "spray rings" practical?

20. Which would be more advisable to buy: sprayer attachments for a small garden tractor that one already owns or a separate, engine-driven, small spray unit?

Chapter 27

APPLICATION EQUIPMENT II

DUSTERS

Dusting equipment makes use of an air stream to carry chemicals in finely divided and dry form onto the plants.

The Parts of a Duster and Their Function

Dusters are much simpler in construction than sprayers and have relatively few working parts (Fig. 207). The typical engine-driven duster is composed of a dust hopper holding from 25 to 200 pounds of dust, with an agitator to keep the dust from caking and also to keep it flowing evenly through an adjustable opening in the bottom of the hopper that connects with the blower unit. The fan-type blower unite creates a powerful air current that picks up the dust as it drops, either in the air chamber or directly against the blower fan blades, and carries it out through the distributor head and delivery tube or tubes. The distributor head may be equipped with baffles to distribute the dust-laden air evenly through all the delivery tubes. For orchard or tree dusting, a single, large, flexible drift tube or an adjustable fish-tail type of delivery tube is generally used. For low-growing trees, multiple, fixed-type drift tubes may be employed. For row-crop dusting, multiple delivery tubes—two to eighteen or more on a dust boom—are used. From one to three are needed per row, depending on the type of coverage desired (Fig. 208).

The nozzles at the end of the delivery tubes are generally of a fish-tail design so as to spread the dust evenly. They may be open-type or closed-type nozzles. A fairly new type known as a whirlpool dust nozzle may be obtained with Messinger dusting equipment. These nozzles throw the dust out in a whirl that is supposed to produce good coverage of plants with only one delivery tube per row. Delivery tubes and nozzles on row-crop dusters are adjustable to fit rows and plants of various widths and heights. A hood-like enclosure over the nozzles will increase dust deposit and allow effective dusting, even with some breeze blowing.

SMALL HAND DUSTERS. These may be of the telescope

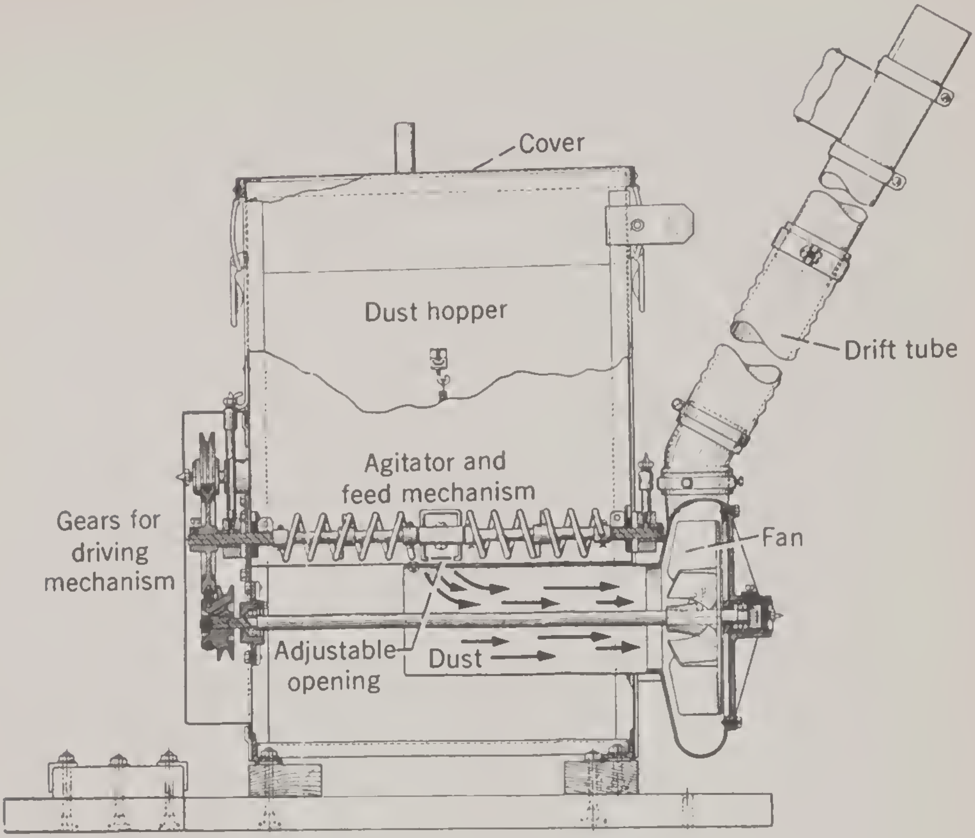


FIG. 207. Cross section of a duster showing working mechanism (courtesy of Niagara Chemical Division, Food Machinery Corp.).

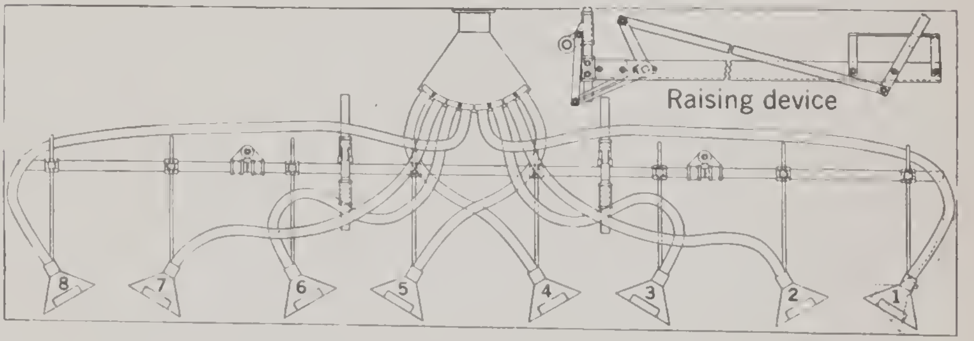


FIG. 208. A dust boom showing nozzles arranged for the proper coverage of four rows (courtesy of John Bean Mfg. Co.).

type and consist essentially of one cardboard cylinder within another; the bellows type; or the plunger type (Fig. 209). In all these types an air stream is produced that picks up the dust and drives it out onto the plants. The dust containers in these dusters may hold from 1 pint to 2 quarts of dust, but they should never be filled more than two-thirds full, because the dust may pour out or come out in too heavy a stream. These dusters are valuable in very small gardens where their prolonged use is not necessary.

Advantages

1. Cheap.
2. Simple to operate.
3. Speedier than sprayer.
4. Lighter and easier to use than sprayer.

Disadvantages

1. Continuous pumping tiresome.
2. Good only for small areas.
3. Dust supply uneven.

KNAPSACK DUSTERS. These are of two types: the bellows type and the rotary fan type. The bellows type is excellent for spot dusting of individual plants or hills. It produces a cloud of dust at each constriction of the bellows. The long discharge tube with fish-tail nozzle is useful in dusting low-growing plants as well as small shrubs and trees. These dusters hold from 5 to 10 pounds of dust and are made of light material so their total weight is not more than about 25 pounds when filled.

The rotary-fan duster operated by means of a crank is preferable for row-crop dusting (Fig. 210). It produces a steady, even cloud of dust when the crank is turned at an even speed while the operator is walking along the row. The delivery tube and nozzle are adjustable to different heights and directions. Double nozzles may be used to cover two rows at a time. Much greater areas may be covered with this type of duster, but it may not give as good coverage as the bellows type unless care is taken to regulate the height and direction of the nozzle so as to blow the dust into the plants from the side instead of from above. Both the above dusters may be quite tiring for several hours of continuous use. The rotary-fan duster is also designed for dusting from mule or horseback.

Advantages

1. Even flow of dust; they have a positive dust-feeding device and an adjustable opening in dust hopper.

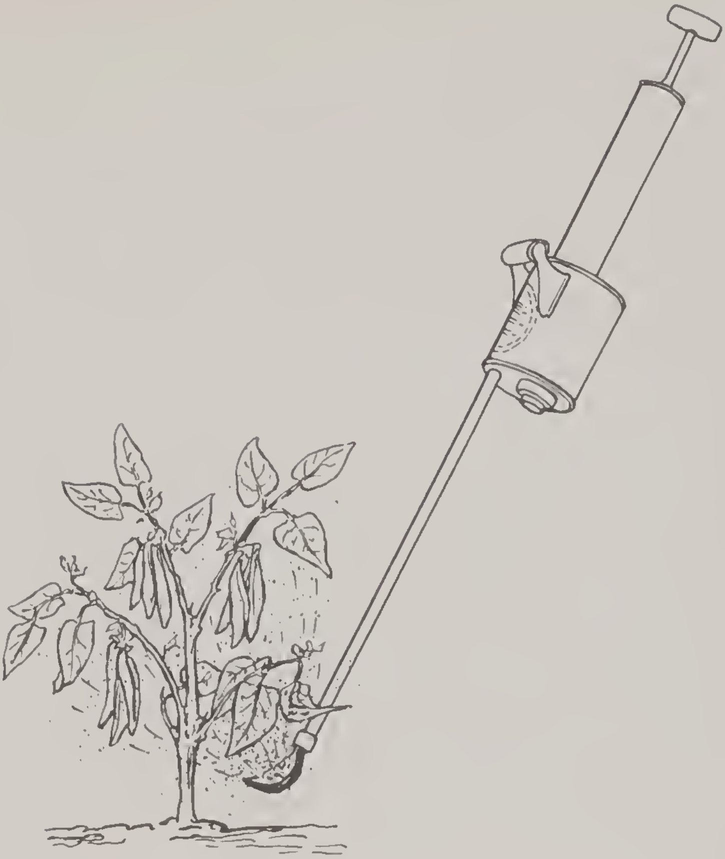


FIG. 209. A plunger type of hand duster.

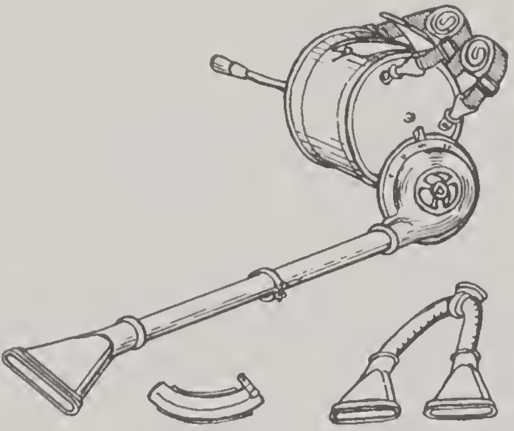


FIG. 210. A rotary fan duster.

2. Can carry enough dust to cover large area.
3. Simple to use.
4. Rapid application.

Disadvantages

1. Much more costly than hand-carried equipment (about $35).
2. Rather tiring for continuous operation.

TRACTION DUSTERS. These may be wheelbarrow-type traction dusters equipped with two to four nozzles for dusting two rows at a time; or larger horse- or tractor-drawn row-crop dusters covering several rows at a time. They work on the same principle as the traction sprayers and have the same limitations. It takes a husky individual to operate the wheelbarrow traction duster for any length of time. Some growers use a horse to pull it. Fairly large acreages may be covered by traction dusters.

Advantages

1. Cheaper than engine-powered dusters.

Disadvantages

1. Steady speed for good dust cloud not always possible, especially at ends of rows.
2. Pushing-type is too tiring.

POWER DUSTERS. These range from small, row-crop wheelbarrow or two-wheeled types with or without engine motive power to powerful row-crop or tree dusters (Fig. 211) pulled by horses or tractor. Some dusters are of the trailer type and operate by power takeoff from the tractor that pulls them. The large dusters generate an even, high-velocity dust cloud and are suitable for protecting large acreages.

Advantages

1. Suitable for large acreages.
2. No water required, so no time wasted in refilling.
3. Speedy—save labor and time.
4. Less trouble—not as many things to go wrong as in a sprayer.
5. Equipment light—heavy tractor equipment not necessary.
6. Cheaper purchase cost than sprayers that can do the same job.

Disadvantages

1. Use limited to suitable weather conditions, especially for tree dusting.

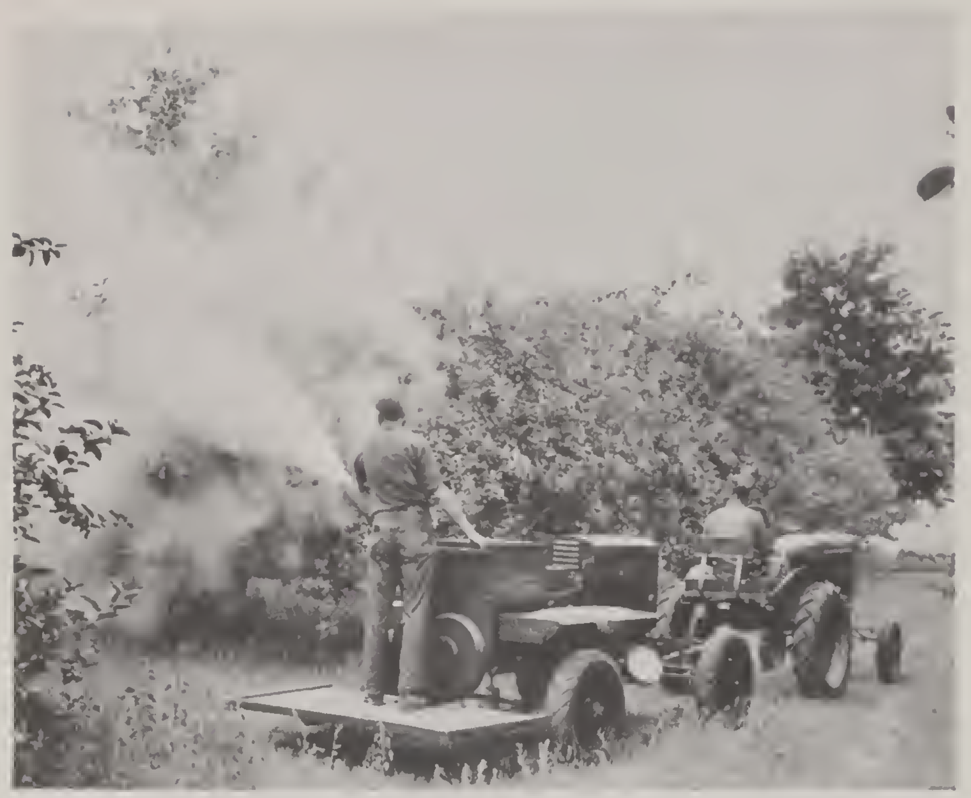


FIG. 211. A tree duster in action in an apple orchard (courtesy of Niagara Chemical Division, Food Machinery Corp.).

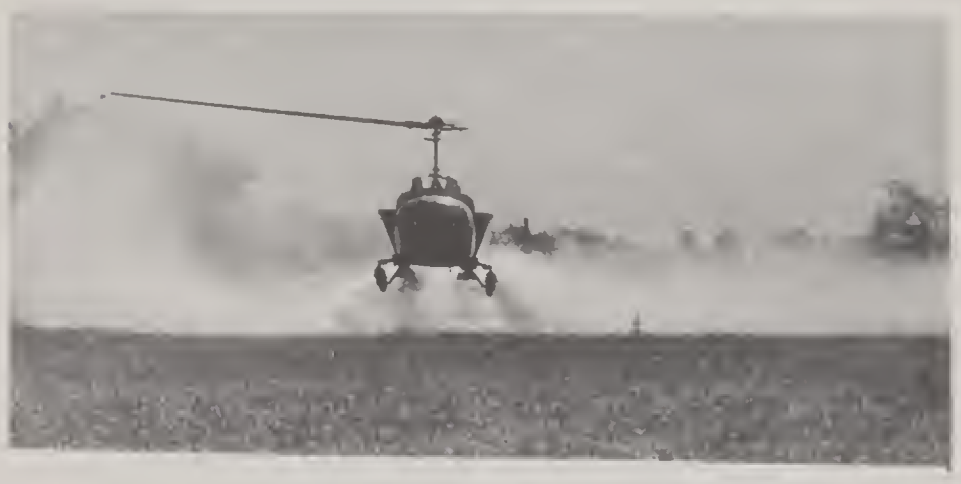


FIG. 212. A helicopter dusting a forage crop (courtesy of Bell Aircraft Corp.).

2. May not give as good control of some insects or plant diseases because of rapid weathering of chemicals.
3. Dusts may carry to other crops and injure them or leave dangerous residues.

AIRPLANE AND HELICOPTER APPLICATION OF CHEMICALS

Custom pest control by means of airplanes or helicopters has gained in popularity (Fig. 212). It is especially suitable for large acreages and inaccessible areas, since it offers an extremely rapid method of application, with coverage of hundreds of acres of crops or forested areas possible in a single day. Dusts, concentrated sprays, or fogs may be applied from the air. For crops, airplane or helicopter dusting has been found more effective than spraying because of better and more even coverage. The down-draft from the wings of the plane or rotors of the helicopter tends to drive the dust down in a swirling cloud so that some coverage on the undersurface of foliage is also obtained. This is not true of sprays, which cover only the top of the foliage. Fog or concentrated mist application of the new organics from planes or helicopters is very effective for space control of flying pests of man and animals and of foliage-chewing insects. It is not suitable for applications of fungicides, because the residual effect is slight and thoroughness of coverage is poor. As little as a pint of material per acre may be applied from the air as a fog or mist.

Airplane application is faster than helicopter application, but the helicopter can go into fields and wooded areas too dangerous for planes to tackle. The helicopter also has the advantage of being able to land for reloading in any small clearing close to the scene of operations, whereas the airplane must have a regular landing field, often miles away from the areas to be treated.

Advantages

1. Large areas may be treated in a comparatively short time (up to 300 acres in an hour of actual dusting).
2. Grower eliminates cost and upkeep of equipment.
3. Grower eliminates use of labor.
4. No crop damage from equipment—the wheels of ground equipment often cause considerable damage to crops.

5. Areas inaccessible to ground equipment or where use of ground equipment is impracticable may be treated.

Disadvantages

1. Applications dependent on weather conditions—planes or helicopters may be grounded by weather conditions, or wind may be too strong for effective application.
2. Grower must depend on contracting party to make applications when needed—this is not always possible.
3. Control usually not as good as with ground equipment.

NEW SPEED EQUIPMENT

These are variously known as speed sprayers, vapo-sprayers, mist blowers, wet dusters, or sprayer-dusters (Figs. 213 and 214). They are or can be adapted to apply solutions, emulsions, suspensions, or dusts. They all make use of an air current to carry the chemicals as a mist or wet dust onto the foliage, and they tend to combine the effectiveness of spraying with the speed of dusting. Some use a high-velocity, low-volume air current (up to 250 miles per hour); others use a large-volume, low-velocity air current. Some of the speed sprayers still use bulky volumes of dilute spray mixtures, but most are now adapted to use concentrated spray mixtures and to apply these evenly at the proper dosage on the foliage or fruit of plants.

The spray nozzles on these machines are placed near the outlet of the adjustable air discharge tube which may be round or of a fish-tail design. The nozzles either atomize the spray into the air stream, or the high-velocity air stream by its shearing effect atomizes the spray and carries it. Sprayer-dusters may function as dusters, as concentrated mist blowers, or as both. When they are used as wet dusters the dust comes out simultaneously with a liquid mist that facilitates dust deposit and aids in residue retention. Mist blowers range from small, portable electrically powered outfits for greenhouse or household use to high-powered outfits for large trees or row crops. These new types of equipment will not completely replace ordinary spraying, but they have certain definite uses and advantages.

Advantages

1. Rapid application—apply spray or wet dust at least four times as fast as hydraulic sprayer with spray guns.

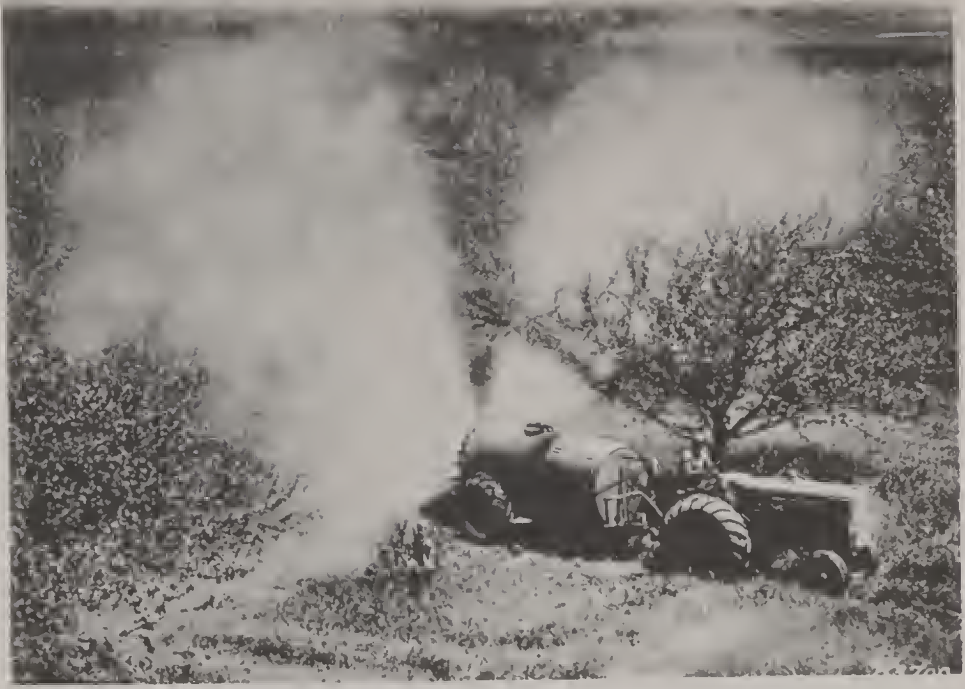


FIG. 213. A speed sprayer in action in an orchard (courtesy of John Bean Mfg. Co.).

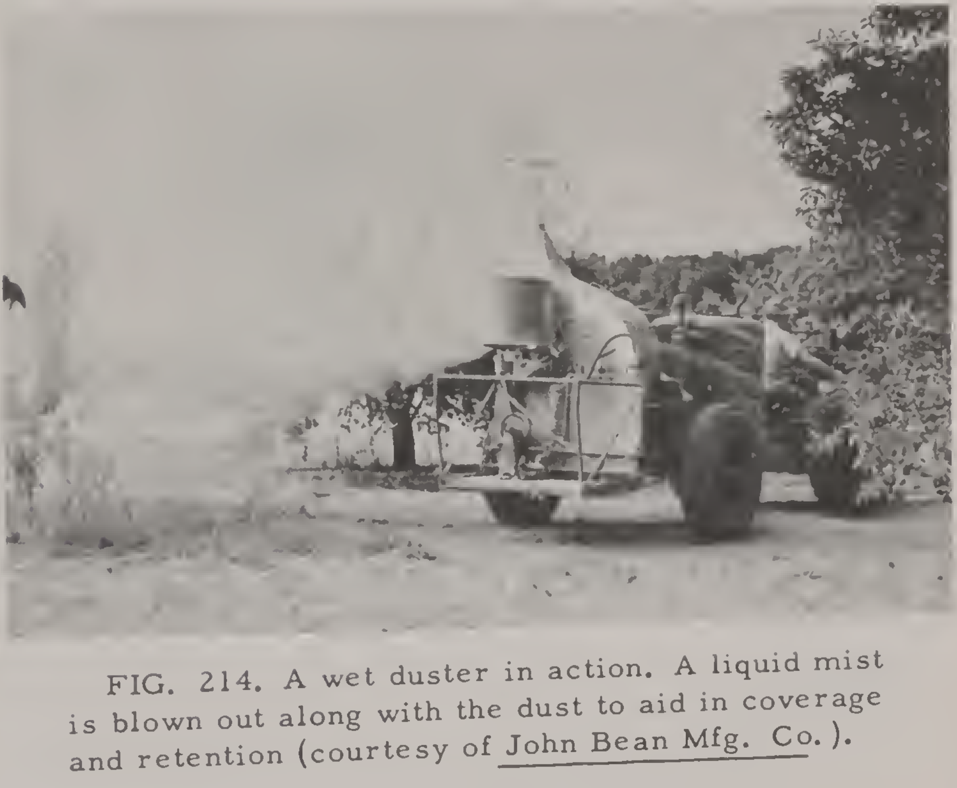


FIG. 214. A wet duster in action. A liquid mist is blown out along with the dust to aid in coverage and retention (courtesy of John Bean Mfg. Co.).

2. Better timing of sprays owing to the increased speed of operation.
3. Lower operational costs—eliminate large amounts of water and labor.
4. Lower material costs—mist sprayer uses only a fraction of the amount of spray that would be necessary to spray the same trees with a hydraulic sprayer.
5. Lower capital investment in truck and blower equipment for results obtained.
6. Excellent for space control of leaf-eating insects, flies, and mosquitoes.
7. May apply as little as 2 to 3 gallons of concentrate evenly on an acre of land. The amount of killing agent is not reduced per given area, but quantity of inert carrier is reduced.
8. Applied in small droplet size—less run-off, uniform coverage.
9. Wet dusters eliminate the need for natural moisture on the foliage and thus broaden application opportunities.

Disadvantages

1. Coverage may not be complete or thorough in the case of large trees.
2. Equipment and dosages still experimental.
3. Mists difficult to confine to area or plants under treatment.

AEROSOL OR FOG APPLICATION EQUIPMENT

Aerosol application equipment consists of special steel containers ("bombs") fitted with a valve and a nozzle or with high-pressure hose and special spray gun and nozzle. There are no working parts: one has merely to open the valve to release the contents of the container in the form of an aerosol or a fog. The carrier is a liquified gas such as "Freon" or methyl chloride in which the active ingredients are either dissolved or emulsified. This liquified gas produces the pressure and atomizing effect on release into the air through a suitable nozzle. The "bombs" should be carried inverted when discharging the aerosol.

Fog generators (Fig. 215), which produce aerosols for space treatments, use superheated oil into which the chemical solutions are injected near the release point to produce the aero-

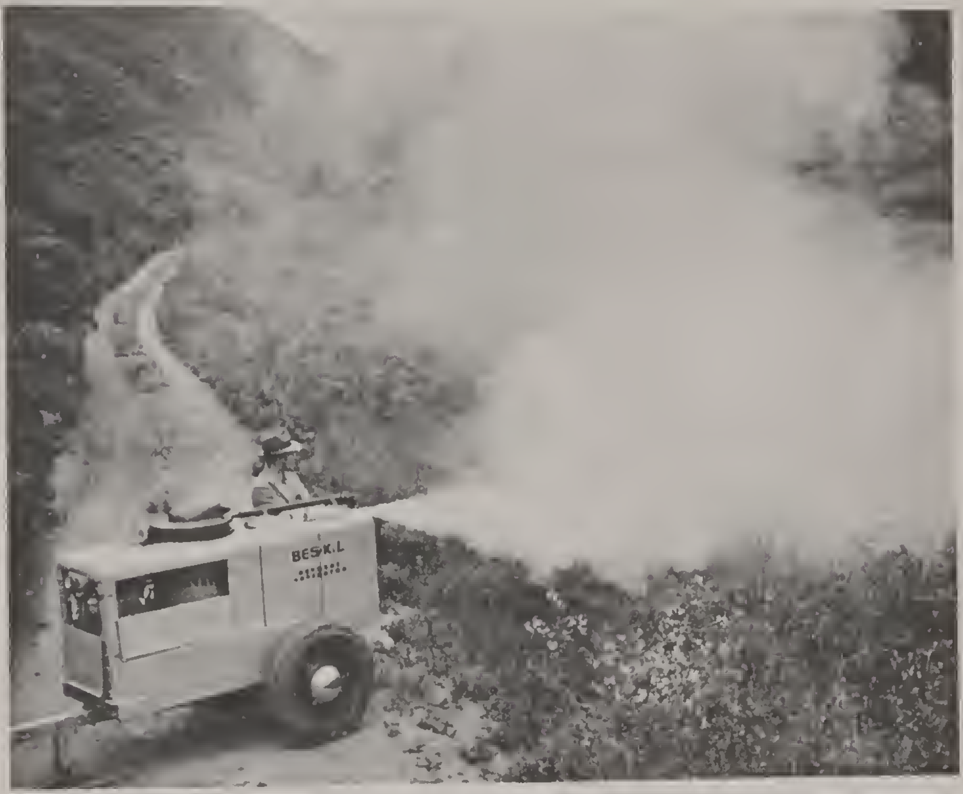


FIG. 215. A fog generator in use for mosquito control (courtesy of Bes-kill Corp.).

sol formation. Under outdoor conditions they depend on natural air currents to drift the aerosol over the crops or through the trees to be protected. Some mist sprayers that use an air blast may very closely approach aerosol atomization.

Aerosols are very promising for insect and red spider control in enclosed places. Under outdoor conditions they have been effective for insect control on canning crops, field crops, vegetables, and in forested areas. They have also been valuable in combination with the new organic insecticides but lack residual effectiveness for space control of flies, mosquitoes, and gnats. Aerosol application has been very successful on row-crop insects when the aerosol is confined temporarily over the plants by a canopy or a light tarpaulin.

Aerosols that have a fairly rapid settling rate are best for outdoor use, since they are not easily carried away by air currents and leave some residual effect on the foliage. Their use in orchards is limited, because air movements interfere with complete coverage, and very little residual deposit is obtained. No effective fungicidal aerosols have been produced, mainly because complete, even coverage and a residual deposit is necessary for disease control.

Advantages

1. Very effective for pest control in enclosed places—disperses like a fumigant.
2. Liquified gas aerosol application requires no expensive equipment.
3. Rapid, easy treatment of enclosed spaces—takes 5 minutes to treat a greenhouse of 100,000 cubic foot capacity.
4. Very small quantities of toxic ingredients can be dispersed over large areas.
5. Creates no residue problem.

Disadvantages

1. Residual effect slight.
2. Bombs must be returned for refills when used up.
3. More expensive in materials cost than other application methods.
4. Not effective for disease control.
5. Outdoor applications limited by weather conditions.
6. Difficult to confine to a definite area outdoors.

HERBICIDE APPLICATION EQUIPMENT

Herbicides for weed control may be applied with any of the spraying or dusting equipment previously described. However, since it was determined that 2,4-D and similar compounds are equally effective when applied in diluted or concentrated form, providing the same amount is applied evenly per acre, low-pressure, low-gallonage pumps are generally used (Fig. 205). Low-pressure pumps also eliminate spray mists that may float away and cause damage to neighboring crops. These pumps may operate at pressures as low as 25 pounds per square inch, and with the proper nozzles and speed (4 miles per hour) may apply as little as 5 gallons of concentrated solution evenly per acre. Nozzles producing a fan-type spray are common in weed-control equipment (Fig. 197). Equipment with compressed air or dry ice to provide low pressures may also be employed in chemical weed control. This equipment may be mounted on mowing machines or on small tractors for use in conjunction with other operations.

FUMIGATION EQUIPMENT

The application of soil fumigants over large acreages has been greatly speeded up and improved in the past few years. The hand-carried and operated injectors (Fig. 216) are suitable for small areas such as greenhouses, cold frames, seedbeds, and small gardens, but are impracticable for larger areas. The new applicators are similar in design to seed planters: the smaller ones may be man-pushed, whereas the larger ones that treat a swath several feet wide are tractor-borne and are capable of treating several acres a day (Fig. 217). The fumigant is piped into the bottom of furrows made by sharp, cultivator-like tines, and sometimes a roller is attached to press the soil down. The fumigant in the form of a liquid flows by gravity, air pressure from a pump, or its own pressure into the furrow at a regulated rate. The rate of flow is adjusted to the speed of the equipment to give the required dosage of the fumigant per acre.

SEED-TREATING EQUIPMENT

This may consist of constant-temperature water baths for dipping seeds for specified times to destroy internal seed-borne diseases by heat; of chemically treated water baths to destroy external seed-borne diseases; of jars with covers for coating seed with a fungicidal dust by shaking seeds and dust together for the control of some seed-borne diseases and soil-borne damping-off diseases; of large, barrel-type dust seed treaters for the same purpose; and of the relatively complex equipment used in the slurry method of pelleting seeds.

The slurry method involves the application of chemical disinfectants to seed in the form of a water suspension or slurry instead of in the dry-powder form. The slurry treater synchronizes the flow of the seed and of the slurry so that every bushel of seed receives the same accurate dosage of chemical. Rapidly revolving agitator blades coat the seed evenly with slurry in the mixing chamber. The seed is not noticeably moist when it leaves the treating chamber and may be sacked and stored at once. The advantages of this machine over the dry-coating machines are (1) the elimination of poisonous or dangerous dusts; and (2) the accuracy and uniformity of the chemical dosage applied.

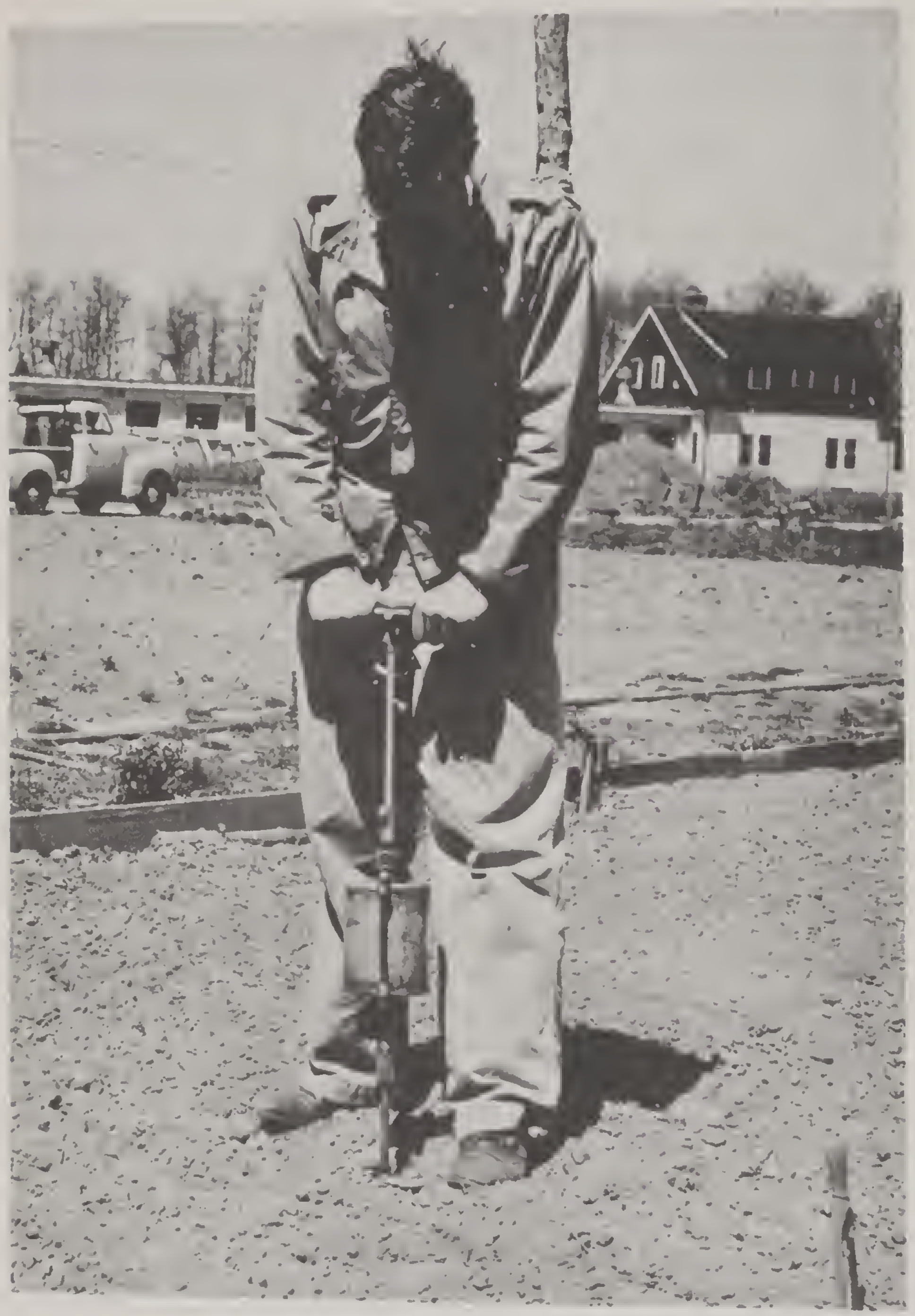


FIG. 216. A hand-operated soil-fumigant injector (courtesy of Innis-Speiden Co.).

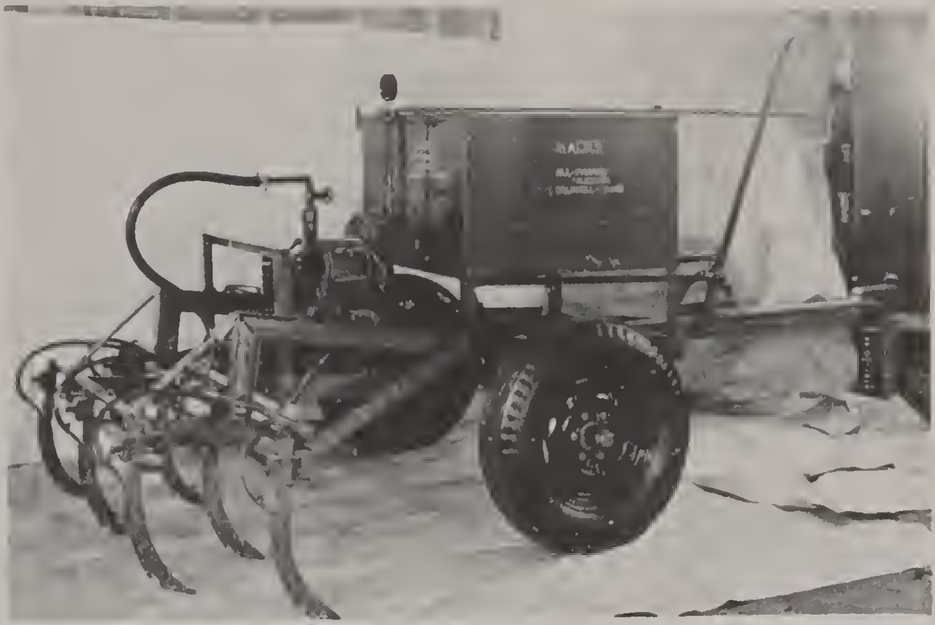


FIG. 217. A trailer type of fumigator suitable for large areas (courtesy of Mack's, Caldwell, Idaho).

FROST PROTECTION EQUIPMENT

Frost protection equipment makes use of one or more of three general principles: (1) conserving heat; (2) stirring the air; and (3) adding heat to the air or to the crops to be protected.

Conservation of heat may be accomplished by the use of some type of covering over the plants, such as glass, burlap or cloth, or paper caps (Hotkaps). Smudge pots that burn crude oil and send a protecting smoke blanket over an area are an old and still valuable device for conserving heat over crops. They are not effective, however, when temperatures drop several degrees below freezing.

Engine- or electrically driven airplane propellers placed on towers keep cold air from settling down on crops and thus prevent frost damage. Planes or helicopters flying back and forth over fields or orchards have also been tried. Air stirring is effective only under light-frost conditions and has not proven too practical.

Heating devices seem to be the most practical method for frost protection. Various types of orchard heaters that burn oil are available. These heaters spaced sufficiently close together may protect crops when temperatures drop as low as 25° F.

The latest and most effective type of heater, developed by Michigan State College, is known as the Frostguard (Fig. 218). This unit burns about 10 gallons of kerosene per hour and is operated by an aircraft-type pump driven by an electric motor that can be operated from a 6-volt storage battery or from a 110-volt, 60-cycle alternating current. The unit consists of a generator-type burner, a stainless-steel combustion chamber, and an aluminum-alloy canopy-type reflector. The intense heat makes the combustion chamber cherry-red. Infra-red rays radiate from this device to the surrounding crops and keep temperatures from dropping. Each unit gives most effective protection within a 100-foot radius, but when four or more units are used together 100 feet apart each unit will protect about an acre because of overlapping radiation.

QUESTIONS FOR DISCUSSION

1. What are the advantages of dusting over spraying? Vice versa?
2. What are the limitations of dusting for crop pest control?
3. Do you consider the present, small, hand-operated sprayers and dusters on the market models of perfection?
4. Which is to be preferred for a small home vegetable garden: a bellows knapsack duster or a rotary fan duster? For a large vegetable garden?
5. What are the chief faults of traction sprayers and dusters?
6. Which will give the better coverage of heavy-foliaged plants: spraying or dusting?
7. What advantages has aerial application of chemicals over ground application? Disadvantages?
8. What factors should be considered in purchasing the new speed-spraying equipment?
9. On what principle do the new mist sprayers operate?
10. If you were a fruit grower, would you switch to speed-spraying equipment? What type, if your answer is yes?

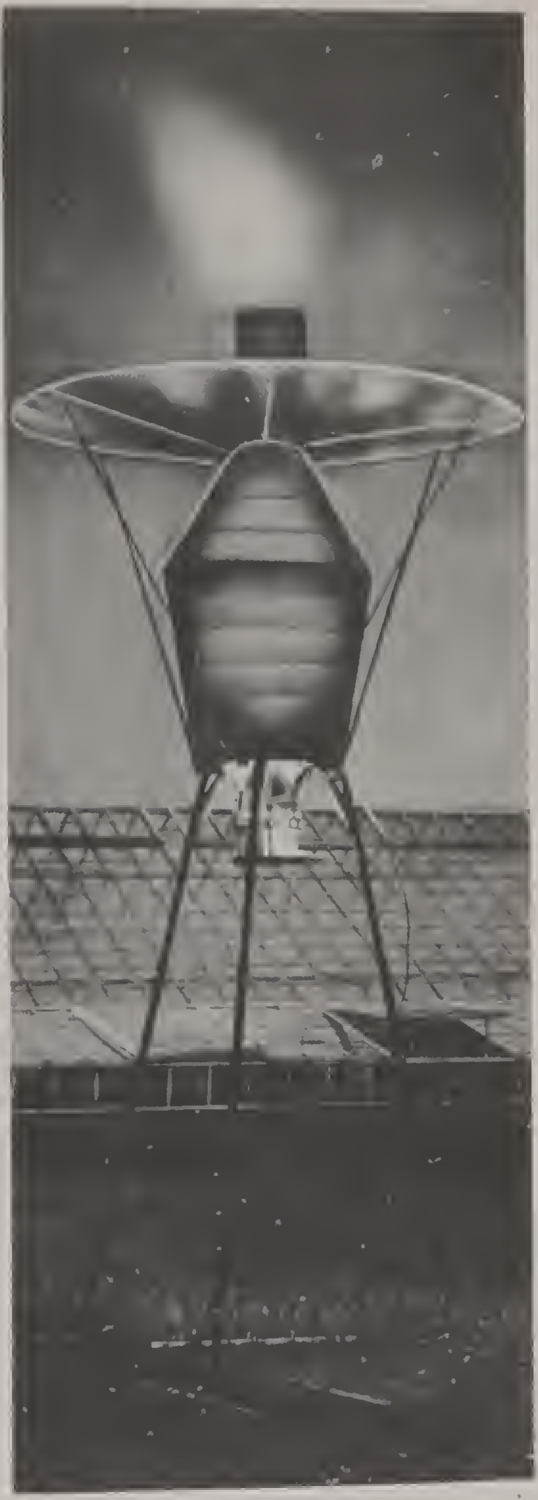


FIG. 218. This type of heater, known as the Frostguard, is very effective in the protection of crops from frosts (courtesy of Evans Industries).

11. Explain how an aerosol applicator works? A fog applicator?

12. Why do chemicals in aerosol form tend to be more effective for certain pests than the same ones in spray or dust form?

13. Why has aerosol application been adopted so readily by greenhouse operators?

14. How does herbicide application equipment differ from insecticide or fungicide application equipment?

15. Why are low-pressure, low-gallonage pumps generally used with 2, 4-D compounds?

16. Why are fan-type sprays usually employed in ground-surface weed-control work?

17. Which is preferable: chemical weed control or flame cultivation of weeds, if either one were practical?

18. Why is soil fumigation becoming more and more practical?

19. How useful is a fumigation chamber to a greenhouse operator?

✓ 20. What advantages has the slurry method of seed treatment over the dry-coating method?

21. Under what conditions would it pay to be equipped with frost-protection devices?

22. Low, protected areas are generally more susceptible to frosts than high, unprotected areas. Why?

23. What are the different ways in which crops may be protected from frosts?

Chapter 28

SELECTION, CARE, AND MANIPULATION OF APPLICATION EQUIPMENT

SELECTION OF APPLICATION EQUIPMENT

In purchasing application equipment the following factors should be considered:

1. The comparative advantages and disadvantages of the different forms in which chemicals may be applied to plants. Chemicals for pest control may be applied to plants as sprays, dusts, air-driven mists, spray-dust combinations, and aerosols. These are discussed in the previous chapters in connection with application equipment. The form best suited to the crop and its protection should be selected.

2. The acreage to be covered or the time allowable for one complete application. The equipment should allow for one complete application in the maximum of 5 days but preferably in 1 to 2 days. This will allow for better control through proper timing or through more frequent applications when necessary.

3. The type of crop to be treated. The machine and its boom, spray guns, or dust nozzles should be adapted for the most efficient and thorough coverage of the crop.

4. Its efficiency in crop protection. This can be determined only by actual experimental trials. The state experiment stations usually carry on such trials and are in a position to advise on relative efficiency. The experience and advice of growers that have used similar equipment in previous seasons is also of great value.

5. The initial cost of the equipment in relation to the returns from the crop to be protected. Under ordinary conditions, new application equipment should pay for itself in the maximum of 5 years, from the standpoint of the added efficiency and crop protection it gives. Where fields are small, individual growers may not be justified in purchasing expensive equipment; it may be more economical for a group to form a “spray ring” and buy an applicator or hire a commercial sprayer; but this should not be at the expense of improper timing.

6. The work and skill involved in operating the equipment. The number of men required to operate the equipment and the

skill required of the operators to do a good job should be considered.

7. Cost of operating the equipment. This involves the cost of the operators, the fuel, and the replacement of parts that tend to wear out.

8. Availability of important parts for inspection, removal, and replacement. This is of primary importance, for when a breakdown occurs much time may be lost or the equipment may be laid up at a critical time for preventing or controlling an outbreak of insects or disease.

9. Pump capacity. The spray pump should be able to supply sufficient volume (gallons per minute) to maintain pressure when all nozzles are open. Pumps with the minimum of 16 gallons per minute capacity will generally handle effectively two spray guns with ordinary nozzles. Spray pumps for row crops should be able to supply, from several nozzles at high pressures, 100 to 125 gallons of spray per acre at 4 miles per hour, whereas those used in weed control should be able to supply as little as 10 gallons per acre or less at low pressures. Dusters should generally be able to apply from 30 to 50 pounds of dust per acre at 4 miles per hour.

10. Operating pressure. For most efficient coverage and penetration, sprayers should be able to operate at pressures from 300 to 600 pounds per square inch. Some may operate up to 800 or more pounds per square inch, but in most cases such high pressures are unnecessary and may put a severe strain on the engine.

11. Tank capacity or dust hopper capacity. More time is lost in refilling sprayers than in any other sprayer operation. The tank or hopper capacity should be maximum from the standpoint of saving time in refilling, but at the same time it should be adaptable to the field conditions and the motive power available. Too heavy a spray load that causes bogging down in wet fields is just as inefficient as too light a spray load necessitating frequent refills.

12. Durability of the equipment. Experience of other growers with the equipment should be investigated, as well as the length of time the company has been in business and its reputation. Application equipment should give good service for at least 5 years without any major repairs or replacements.

13. The drain plug in the tank should not be placed so that one has to crawl under the machine every time it has to be removed or replaced in cleaning the equipment.

CARE OF EQUIPMENT

The proper care of application equipment will add many years to its useful life and will help to avoid serious breakdowns that may interfere with the proper timing of applications. The following practices will help keep equipment in good running order:

1. Lubricate thoroughly all working parts before each day's work. Check especially the lubrication of the cylinder and piston assemblies, since these parts usually get the hardest wear.
2. Always add materials through the strainer in the spray tank; this will help prevent valve trouble and nozzle clogging.
3. At the end of each day's use wash the tank carefully and run clear water through the pump, hose, and spray nozzles for a minute or two. This is done to prevent corrosion of parts and valve sticking when the sprayer is used again.
4. Clean outside parts of sprayer of spray residue that may produce corrosion.
5. At the beginning of the season check piston packing, gaskets, and valves. Replace worn out parts if necessary.
6. Drag the hose as little as possible. If hose is being dragged, keep alert to the possibility of snagging it on an obstruction and snapping it off. See that hose does not rub against the wheels when it is wound up. Many a good hose has been ruined by being ground against a wheel.
7. At the end of the season clean sprayer thoroughly: drain all water from the engine, pump, and tank; disconnect the hose and run lubricating oil through the pump only (oil rots rubber hose); lubricate thoroughly all external working parts, spray gun and nozzle parts; drain oil from engine and pump and replace with new oil; coat with heavy oil or grease all parts subject to rusting; and store hose in a cool, dark place after completely draining it.
8. Dusting equipment, when being used or being prepared for storage, in general, should receive about the same treatment for lubrication of working parts and protection from corrosion as spraying equipment.
9. Use a separate sprayer for 2,4-D; if this is not possible clean the sprayer (especially the screens) thoroughly after use. Fill the tank with hot water, add 1 quart of household ammonia to each 25 gallons of water, spray out a small amount

and let the remainder stay in the tank overnight. Double or triple the soaking time with cold water. Drain and rinse several times with hot soapy water, spraying out a small amount each time. Flushing with ample hot soapy water may be sufficient if non-sensitive crops are to be sprayed subsequently.

SPRAYING AND DUSTING TECHNIQUES

The effectiveness of application equipment is based on the skill of its operators. The same piece of equipment may give good, fair, or poor control of pests as determined by its operator's ability to do a thorough job at the right time. There is no better way to learn the correct techniques of application than through watching, and practicing continuously under the guidance of an experienced operator. Only after considerable practice can a man be relied on to know what good coverage is and to be able to attain it.

Spray Patterns and Their Adjustment

The nozzle has an important bearing on the effectiveness of the whole spraying operation. Almost any type of desired spray may be obtained by using the right nozzle or by adjusting the nozzle. The four types of spray patterns that may be produced by spray nozzles are: hollow-cone spray, solid-cone spray, flat spray, and solid-jet spray.

The hollow-cone type of spray (Fig. 219A) is the one most

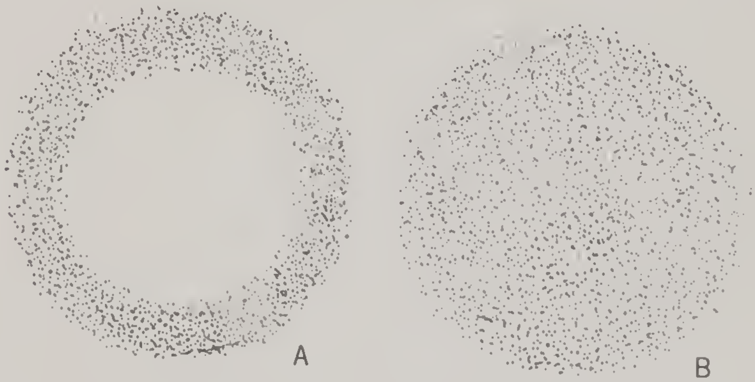


FIG. 219. A, hollow-cone spray pattern; B, solid-cone spray pattern.

often used in close-up spraying. The angle of the cone may be made either narrower or wider by varying the depth of the eddy chamber. A thicker washer will increase the depth of the eddy chamber and in turn give a narrower spray cone. Too wide a spray-cone angle reduces carrying distance and spraying efficiency. The solid-cone spray (Fig. 219B) is produced by boring a hole somewhat smaller than the disc hole in the center of the vortex plate. This type of spray tends to increase carrying distance and spray coverage and is useful in applying herbicides to the bark and cut surfaces of woody perennials.

The flat or fan-shaped spray (Fig. 197) most useful in weed-control work is produced by a nozzle without a vortex plate and with a grooved disc. The solid-jet spray is produced by a nozzle without a vortex plate. It is useful for long-distance spray coverage such as reaching the tops of tall trees. All-purpose types of spray guns have a screw type of shutoff valve that increases the depth of the eddy chamber as it is opened. This makes possible all types of sprays from misty, hollow cone with a narrowing angle to solid jet.

Spray Adjustments

The type of spray produced, its carrying power, its volume, and its fineness may be adjusted to some extent by various manipulations of the spray pump and the spray nozzles.

Spray volume is increased by:

1. Increasing the pressure.
2. Increasing the size of the disc orifice.
3. Increasing the number of nozzles.

Spray fineness is increased by:

1. Increasing the pressure. In hand-operated equipment this is done by pumping faster or by using a disc with a smaller orifice. In power equipment this is done by increasing the tension on the spring in the pressure regulator.

Carrying distance of spray is increased by:

1. Increasing spray pressure. In the case of hollow- or solid-cone sprays, pressures beyond 800 pounds per square inch actually tend to decrease carrying power, because the spray is broken up into so fine a mist that it does not have the body to carry as far as a coarser spray under lower pressures.

2. Reducing the angle of the spray cone by increasing depth of the eddy chamber.
3. Removing the vortex plate. This produces a solid-stream spray. Solid-stream sprays as produced by shade-tree guns continue to give increased carrying distance beyond 800 pounds pressure.
4. Using a larger disc orifice, but at the same time maintaining or increasing the previous pump pressure.

Techniques in Spraying Plants

AMOUNT TO APPLY. Determine the best type of spray boom, spray mast, or spray gun and nozzles to use for the job. Keep in mind that an even, thorough coverage is required with the minimum of waste. A light dripping immediately after an application indicates good coverage without excessive use of spray; no dripping may mean insufficient coverage; and heavy dripping means too heavy an application and waste. The speed of movement of the spray rig or that of the spray gun governs the amount of spray applied.

Tree-Spraying Techniques

1. In spraying a tree from the ground with a spray gun spray the tree first from underneath, if necessary; then start on the outside at the point opposite the sprayer and work around the tree towards the sprayer so as not to end up with the hose wrapped around the trunk. When the tree is completely sprayed, the operator should be able to move directly to the starting point on the next tree (Fig. 220).
2. When spraying the outside of a tree, treat it as a solid object and the spray gun like a paint brush. Move the spray gun at a steady speed in vertical up and down sweeps, overlapping slightly each time to obtain complete coverage (Fig. 221).
3. Hold the spray gun a moment at the top end of each sweep and flick it slightly if necessary to get good top coverage.
4. As the spray gun is brought down, back away a step or two, if necessary, to avoid sticking the end of the spray gun into the tips of the lower branches and thus miss covering the tips and possibly causing injury to foliage or fruit.

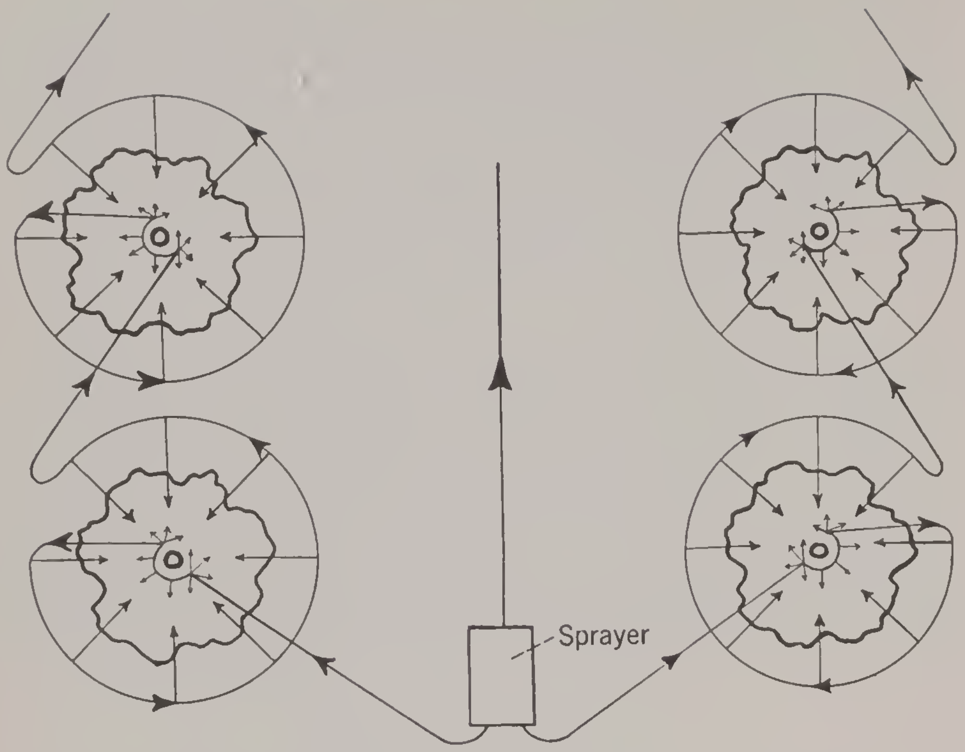


FIG. 220. Procedure in spraying trees from the ground both from underneath and from the outside. Arrows extending from lines indicate direction of spray.

5. The speed with which the spray gun is moved will determine the coverage. Gauge the speed so that the foliage is wetted and a light dripping results.

6. It is not wise to attempt to spray when there is a strong breeze (as indicated by a flag standing straight out); but if an application is essential, a spray may be put on from the windward side only. Never spray directly into the wind; most of the material will be wasted, and the operator will be covered with it.

7. Take note of the wind direction. When the point where the spray gun begins to face into the wind is reached, cover as much of the tree as possible from that angle, shut off the spray gun, shift to the same position on the opposite side of the tree, face the last sprayed portion, and continue application around the tree (Fig. 222).

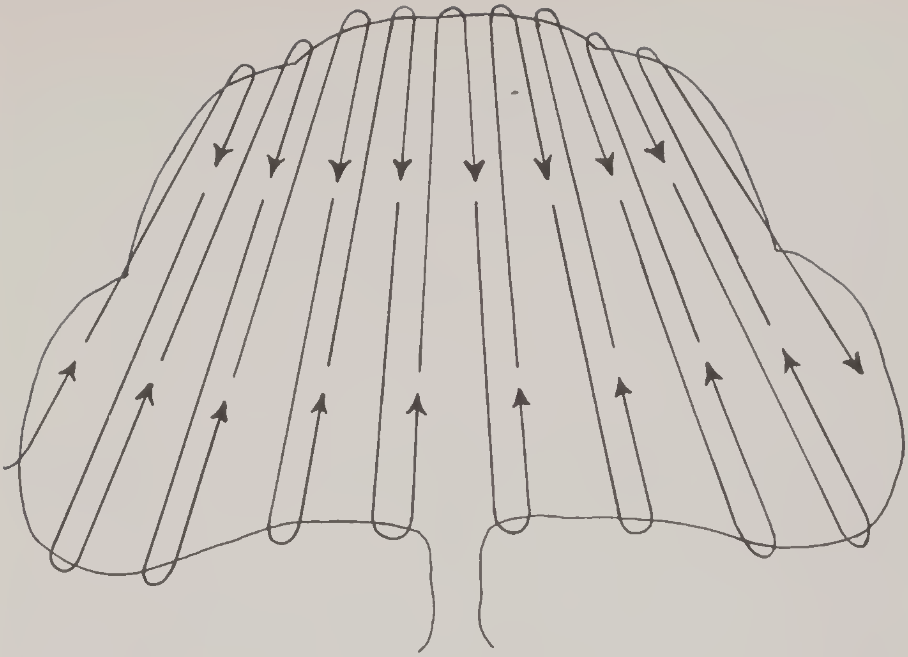


FIG. 221. Direction of spray-gun movements in spraying a tree from the outside.

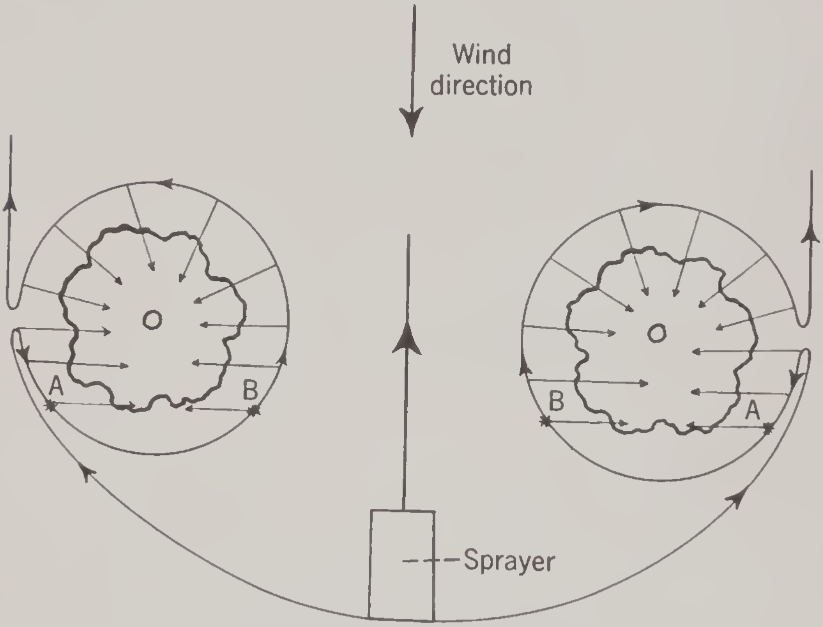


FIG. 222. Procedure in spraying in order to cover the tree and not operator in breezy weather. A, shut gun off and walk to point B; B, turn gun on, point gun in direction indicated by arrows.

SPRAYING TREES WHILE RIDING. Two methods may be used in spraying trees with the operators mounted on the equipment. In the first method one man stands on top of the tank on a special platform and covers the top part of each tree on one side as the spray rig moves by. The other man stands on a low platform mounted behind the spray tank and covers the lower part of each tree. In this operation the spray rig moves steadily from tree to tree with an increase in operation speed, but with some loss in thoroughness of coverage (Fig. 223).

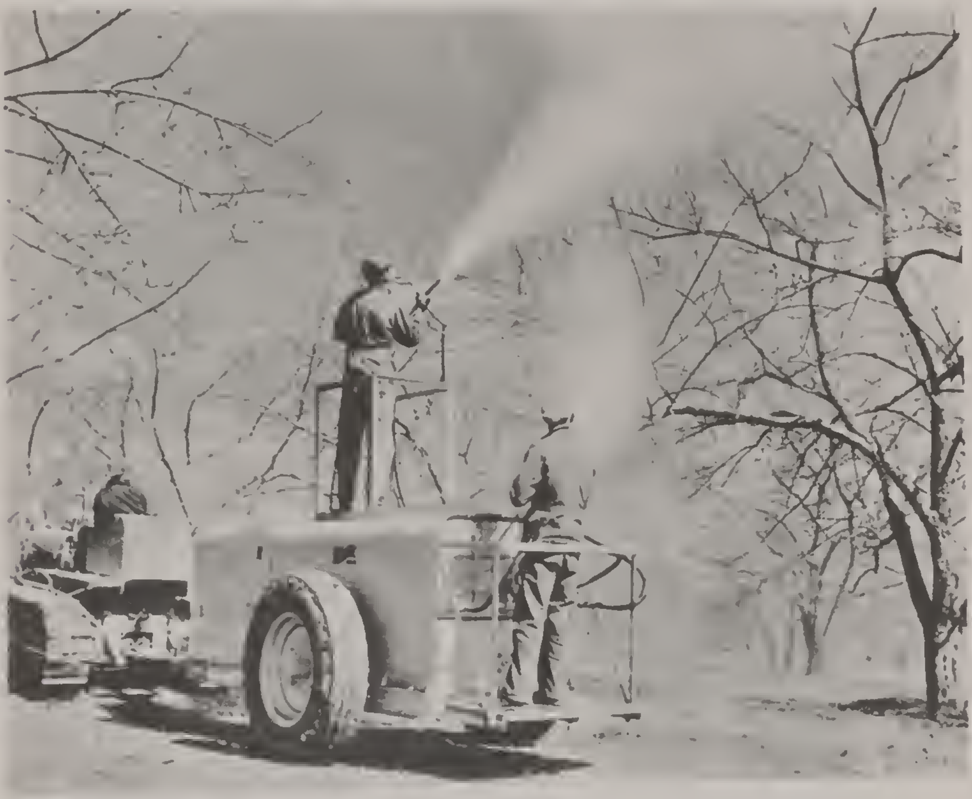


FIG. 223. A method of tree spraying that increases the speed of coverage with some loss in thoroughness (courtesy of A. B. Farquhar Co.).

In the second method, applicable only to trees that are fairly close together, both men stand on the platform on top of the tank. Each one covers half of each tree on his side of the spray rig as it moves by. This method still further increases the speed of application but usually with additional loss of thoroughness.

USE OF SPRAY MASTS. The use of spray masts or booms on which are mounted multiple nozzles to give coverage of either half of each tree in one row or half of each of the trees in two rows is another modification to decrease labor and to increase the speed of operation (Fig. 198). The nozzles on these masts may be adjustable and may be operated by a man while the application is being made, or they may be fixed and require no operator other than the man driving the tractor. The speed of driving regulates the amount of spray applied. Speeds of 2 to 4 miles per hour are usual. The slower speeds are used later in the season when the foliage becomes dense and better coverage is needed.

MANIPULATION OF SPEED-SPRAYING EQUIPMENT. Speed sprayers may use ordinary spray dilutions or concentrated sprays. Care should be taken to get good coverage of the tree tops by placing deflectors to direct more of the air stream towards the tree tops and by arranging the nozzles to give greater volume to the top parts of the air stream. Greater care must be used to obtain as good coverage and as good deposits with concentrated sprays as are obtained with diluted sprays. In using concentrated sprays the trees should be wetted only to the point of drip; this requires speeds from 0.8 to 2 miles per hour, depending on the denseness of the foliage. The best speed of operation to obtain good coverage can only be determined by close observation of the wetting of the bark, foliage, and fruit. Speed-spraying equipment may also be adapted for the treatment of field and vegetable crops.

Pointers on Dusting

Dusting is most successful when the foliage is wet and the air is calm. Such conditions are usually most prevalent in the evening or early morning. In tree dusting, the drift tube is so manipulated that the dust cloud completely envelopes the tree while the duster moves along at a steady pace. The tree dusters that have single or double fish-tail discharge heads that are adjustable while dusting are satisfactory mainly for small-sized trees. The latest models of dusters that use large volumes of air at low velocity and have a precision-type feed into the air stream tend to give better and more uniform distribution of the dust.

Calculating Dosages on a per Acre Basis

The calculating of dosages on a per acre basis is especially important in row-crop spraying and weed spraying with the new herbicides. The correct amount of each chemical should be applied to the plants on a per acre basis and not at the recommended dilution of the chemicals on a per 100-gallon basis which may be rendered inaccurate by the pressure, speed of travel, and size of the disc holes. It is important to be able to check on the gallons per acre that a piece of equipment puts out so that the correct amounts of chemical may be applied to the plants by changing the concentration in the spray tank.

Method for High-Gallonage Applications

The following method is most applicable to high-gallonage row-crop or ground-covering equipment:

1. Start the spray motor, be sure everything is working properly and that nozzles are not clogged.
2. Fill the tank completely with solution of approximately the proper concentration.
3. Open the valve to the spray boom.
4. Drive 40 rods at normal tractor speed (approximately 3 to 4 miles per hour).
5. Close the valve at the end of 40 rods and measure the number of gallons used by measuring the amount needed to fill the tank completely again.
6. Multiply the number of gallons used by 66.
7. Divide this figure by the width in feet of the spray boom.
8. The answer is the number of gallons of solution that the machine will apply per acre, providing spray pressure and speed of travel are maintained.
9. The right amount of chemical to be applied per acre is then added to each unit number of gallons that is applied per acre. For example: if the sprayer holds 300 gallons, if its output at a certain speed and pressure is 150 gallons per acre, and if 2 pounds of actual DDT per acre are to be applied, 8 pounds of 50 per cent DDT (wettable) in a full spray tank should be added.

Method for Low-Gallonage Applications

The following formula is used with low-gallonage, low-pressure equipment:

$$\text{GPA} = \frac{\text{GPH per nozzle}}{0.01 \times \text{MPH} \times \text{inches spacing}}$$

where

GPA = gallons per acre;
GPH = gallons per hour per nozzle = cc. per minute x 0.016 or ounces per minute x 0.47;

MPH = miles per hour (3 to 4 is usual tractor rate: calibrate with auto);
Inches spacing = inches between nozzles (measure with ruler).

To test a given piece of low-gallonage equipment to be used with definite-sized nozzle-disc holes at a constant, set pressure:

1. Turn sprayer on.
2. Measure quantity of liquid delivered from 1 nozzle in 1 minute either in cc. or in tenths of ounces (graduate should not be more than 1 inch in diameter for the sake of accuracy and should be made of plastic to avoid breaking).
3. Obtain value for GPH as shown above.
4. Substitute known factors in formula and calculate the GPA.
5. Where any of the three factors is known, the fourth can be calculated from the above formula.

Example: If by the use of the above formula it is determined that the sprayer delivers 10 gallons of spray per acre and 1 pound of actual 2,4-D per acre is to be used, 1 pound of actual 2,4-D should be added for each unit of 10 gallons of water that the spray tank holds.

Method of Diluting Dust or Spray Concentrates to Correct Strength for Application

Almost everyone working with pest-control chemicals has occasion to make definite dilutions of dusts or sprays, starting with the concentrated materials containing a known percentage of the active ingredients. The procedure for determining how much of the concentrated material should be mixed with how much of the diluting ingredient to make a definite amount of insecticide or fungicide of the required strength is as follows:

1. Determine how much of the actual active ingredient is needed in the amount of diluted product desired.
2. Determine how much of the active ingredient is present in 1 unit (pound, gallon, cc., or gram) of the concentrated product.
3. Divide the amount present in 1 unit of the concentrated product into the amount needed in the diluted product to determine the number of units of the concentrated product that will have to be mixed with the diluting agent to obtain the desired dilution.
4. The amount of diluting agent required is determined by subtracting the amount of concentrated material needed from the total amount of diluted product desired.

> Example: Make 100 pounds of a 0.75 per cent rotenone dust from a 5 per cent rotenone powder concentrate using pyrophyllite as the diluting agent.
>
> Solution: 100 x 0.0075 or 0.75 pounds of actual rotenone will be needed in the 100 pounds of diluted dust. Each pound of the concentrated powder contains 0.05 x 1 or 0.05 pounds of rotenone; therefore, 0.75 ÷ 0.05 or 15 pounds of the 5 per cent rotenone powder is needed for mixing with 100 - 15 or 85 pounds of pyrophyllite to produce 100 pounds of a 0.75 per cent dust.

The Timing of Fruit Sprays

Since the timing of sprays because of weather and climatic conditions varies greatly in different areas of the country and even in different areas of a state, growers should follow application schedules distributed by their own local agricultural agencies. However, to understand an application schedule, the stages of plant growth that may be referred to therein should be clearly understood by every grower.

1. Dormant Spray. In the late winter or early spring before the buds begin to swell.
2. Green-Tip Spray (Fig. 29). When bud tips begin to show green. Some dormant spray materials may still be applied at this stage.
3. Delayed Dormant Spray (Fig. 224). When green leaves are from 1/4 to 1/2 inch out. "Superior" oils may still be used; otherwise use summer-spray materials.

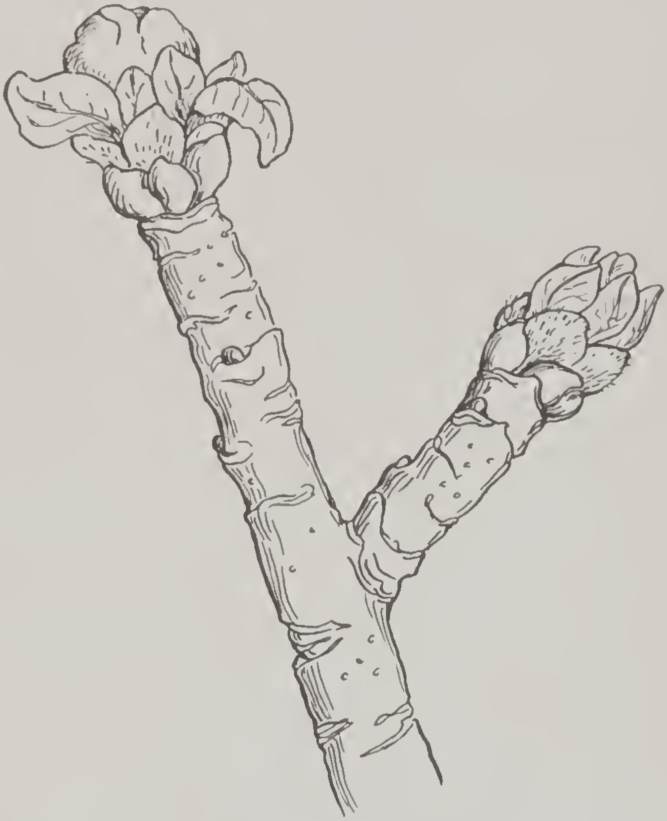


FIG. 224. Delayed dormant stage of apple growth.

4. Pre-Pink Spray or Cluster-Bud Spray. When flower buds are beginning to separate from the cluster.

5. Pink Spray (Fig. 225). When flower buds show pink or other petal color.

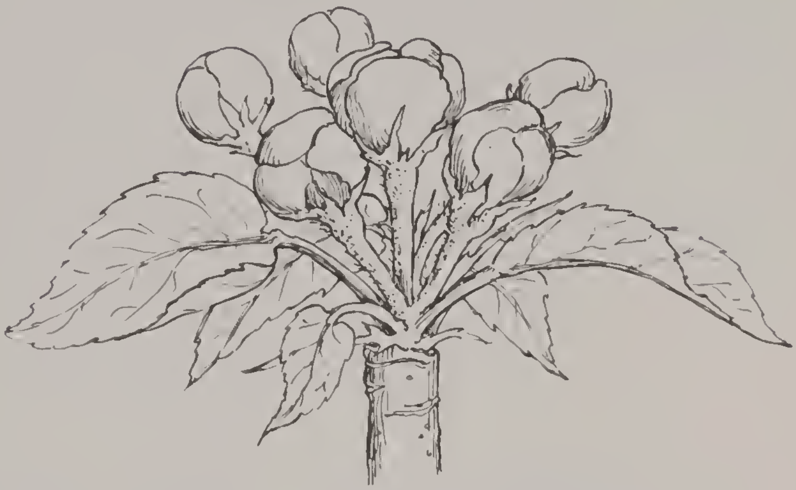


FIG. 225. Late pink stage of apple growth.

6. Calyx or Petal-Fall Spray. When about 3/4 of the petals have dropped.

7. Shuck Spray (Fig. 226). Stone fruits only, when the dried-up blossoms remains (shucks) are splitting and falling off the small fruits.

8. First Cover Spray. About 1 week to 10 days after the calyx or shuck spray.

9. Other Cover Sprays. As many as five at definite intervals (usually 10-day to 2-week intervals), depending on the insects or diseases present.

SPECIAL CONSIDERATIONS IN MAKING APPLICATIONS. The application of poisonous chemicals on fruits and seed crops should be avoided during the blossoming period so as not to harm bees and other insects that are of great value in the cross-pollination of the crops.

In most spray or dust schedules for fruits and vegetables, combinations of insecticides or of insecticides and fungicides save time and effort in the control of the several different types of insects as well as of diseases to which the crops may be subject. From the standpoint of plant injury and effectiveness it is important to know which combinations are compatible and which are not. Table 50 lists the compatibilities of the majority of the common insecticides and fungicides.

TABLE 50

COMPATIBILITY OF COMMON SPRAY MATERIALS

	Lead arsenate	Calcium arsenate	Paris green	Cryolite	Rotenone	Pyrethrum	Nicotine	DDT	Chlordane	BHC	Toxaphene	TEPP	Parathion	Summer oils	Dormant oils	Dinitro compds.	Lime sulfur	Wettable sulfur	Lime	Fixed coppers	Bordeaux	Dithiocarbamates
Lead arsenate		OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	Q	OK	OK	Q	Q	D	OK	OK	OK	OK	OK
Calcium arsenate	OK		OK	NO	D	D	OK	OK	Q	NO	Q	NO	Q	OK	Q	Q	OK	OK	OK	OK	OK	Q
Paris green	OK	OK		NO	NO	NO	OK	OK	OK	OK	OK	NO	Q	Q	Q	Q	NO	NO	OK	OK	OK	NO
Cryolite	OK	NO	NO		OK	OK	NO	OK	OK	OK	OK	Q	Q	OK	Q	Q	NO	OK	NO	Q	NO	OK
Rotenone	OK	Q	NO	OK		OK	OK	OK	OK	OK	OK	Q	OK	OK	Q	Q	NO	OK	NO	OK	OK	OK
Pyrethrum	OK	Q	NO	OK	OK		OK	OK	OK	OK	OK	Q	OK	OK	Q	Q	NO	OK	NO	OK	OK	OK
Nicotine	OK	OK	OK	NO	OK	OK		OK	Q	Q	OK	Q	OK	OK	Q	Q	OK	OK	OK	OK	OK	OK
DDT	OK	OK	OK	OK	OK	OK	OK		OK	OK	OK	OK	OK	OK	OK	OK	NO	OK	NO	OK	OK	OK
Chlordane	OK	Q	OK	OK	OK	OK	Q	OK		OK	OK	OK	OK	OK	OK	OK	Q	OK	NO	OK	Q	OK
BHC	OK	NO	OK	OK	OK	OK	Q	OK	OK		OK	OK	OK	OK	OK	OK	NO	OK	NO	Q	NO	OK
Toxaphene	OK	Q	OK	OK	OK	OK	OK	OK	OK	OK		OK	OK	OK	OK	OK	Q	OK	Q	OK	Q	OK
TEPP	Q	NO	NO	Q	Q	Q	Q	OK	OK	OK	OK		OK	OK	OK	Q	NO	OK	NO	Q	NO	Q
Parathion	OK	Q	Q	Q	OK	OK	OK	OK	OK	OK	OK	OK		Q	OK	Q	Q	Q	NO	OK	Q	OK
Summer oils	OK	OK	Q	OK	OK	OK	OK	OK	OK	OK	OK	OK	Q		OK	NO	NO	NO	OK	OK	OK	OK
Dormant oils	Q	Q	Q	Q	Q	Q	Q	OK	OK	OK	OK	OK	OK	OK		OK	NO	Q	Q	OK	OK	OK
Dinitro compounds	Q	Q	Q	Q	Q	Q	Q	OK	OK	OK	OK	Q	Q	NO	OK		Q	Q	Q	Q	Q	OK
Lime sulfur	D	OK	NO	NO	NO	NO	OK	NO	Q	NO	Q	NO	Q	NO	NO	Q		OK	OK	NO	NO	Q
Wettable sulfur	OK	OK	NO	OK	OK	OK	OK	OK	OK	OK	OK	OK	Q	NO	Q	Q	OK		OK	OK	OK	OK
Lime	OK	OK	OK	NO	NO	NO	OK	NO	Q	NO	Q	NO	NO	OK	Q	Q	OK	OK		OK	OK	Q
Fixed coppers	OK	OK	OK	Q	OK	OK	OK	OK	OK	Q	OK	Q	OK	OK	OK	Q	NO	OK	OK		OK	Q
Bordeaux	OK	OK	OK	NO	OK	OK	OK	OK	Q	NO	Q	NO	Q	OK	OK	Q	NO	OK	OK	OK		Q
Dithiocarbamates	OK	Q	NO	OK	OK	OK	OK	OK	OK	OK	OK	Q	OK	OK	OK	OK	Q	OK	Q	Q	Q	

OK=fully compatible; Q=compatibility questionable; D=compatible, but may decompose on standing for any length of time; NO=not compatible.

(After D. E. H. Frear, Agr. Chemicals, 4:5, 1949.)

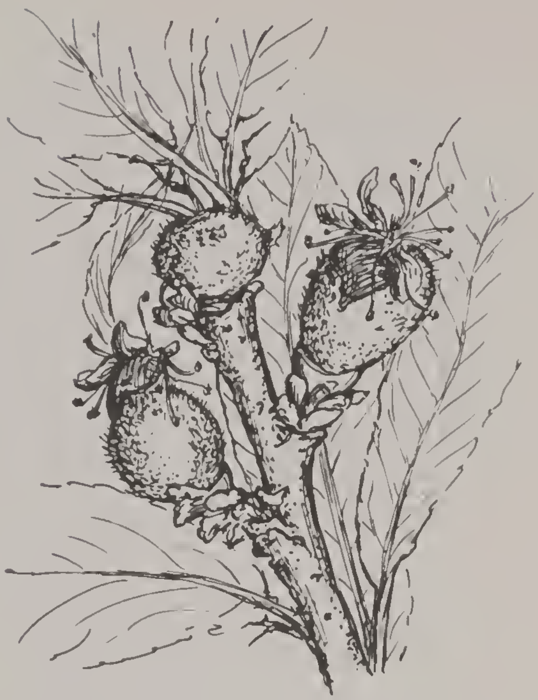


FIG. 226. Late shuck stage of peach growth, best time for spray application.

QUESTIONS FOR DISCUSSION

1. In what form are chemicals most effectively applied to plants, taking into consideration coverage and retention?
2. What are the advantages of using equipment that allows complete coverage of an orchard or field in a day or two?
3. What might growers do if individually they cannot afford to purchase an efficient applicator, or if their fields are too small to warrant the purchase of such equipment?
4. How does one go about determining the efficiency of a machine?
5. Can an unskilled operator do a good job with modern spray equipment?

6. Should a grower be able to inspect, remove, and replace parts in his application equipment himself, or should he use the services of a qualified mechanic as we do with our automobiles?

7. Of what significance is pump capacity in a sprayer?

8. One gets decreased carrying distance with pressure beyond 800 pounds per square inch with the standard hollow-cone nozzle. Why?

9. What should determine the tank or hopper capacity desirable in a sprayer or duster?

10. Discuss the usefulness of each of the four types of spray patterns that may be produced by using the proper nozzle.

11. How should one go about narrowing the angle of the spray cone on a standard nozzle?

12. Would using a smaller disc orifice without any increase in pressure produce a finer spray?

13. What type of spray is obtained when a vortex plate is removed from a standard nozzle?

14. Why should a sprayer be cleaned carefully after each day's work?

15. What are the dangers of using 2, 4-D in a sprayer also employed for other purposes?

16. What factors should be considered while a tree is being sprayed?

17. Explain the techniques of spraying a tree with the wind from the south.

18. Why do very few growers spray trees from the ground?

19. What are the limitations of spray masts in tree spraying?

20. Why must greater care be used in applying concentrated sprays from mist sprayers than in applying diluted sprays from standard sprayers?

21. Under what conditions might dusting be as effective as spraying?

22. In your opinion, what type of equipment can be relied on to give the best coverage of orchard trees? Row crops? Grain or forage crops? Forested areas?

23. What are the limitations of spray schedules?

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GLOSSARY

Acaricide. Any chemical or agent used to destroy mites and ticks.

Acervulus. A cushion-like mass of conidiophores and conidia.

Active ingredient. The actual toxic agent present in a formulation.

Aerosol. A colloidal suspension of solids or liquids in air.

Alternate host. The other species of plant that is necessary for the completion of the life cycle of some insects and plant disease-producing organisms.

Animal. Any organism that belongs to the animal kingdom.

Antennae (sing. antenna). Paired, sensory, segmented structures found on each side of the heads of insects and of some related forms.

Appendage. Any structure attached to a part of the body of an organism.

Ascospores. Spores produced in an ascus.

Ascus (pl. asci). A sac-like container of ascospores, generally eight.

Asexual reproduction. Vegetative reproduction from plant parts other than seeds, or from spores produced by simple budding as in the imperfect stage of a fungus.

Autoecious. Completing life cycle on only one host. Term used with rusts.

Bacteria. Microscopic one-celled plants without chlorophyll.

Bactericide. Any substance that destroys bacteria.

Basidiospores. Spores produced on a basidium.

Basidium. A spore-producing, club-shaped hypha, usually giving rise to four basidiospores.

Biological control. Control of pests by means of predators, parasites, and disease-producing organisms.

Blight. A disease that causes the rapid discoloration and death of leaves, flowers, twigs, etc.

Brood. Offspring of approximately the same age arising from a single species of animal. Generally used with insects or birds.

Callus. Tissue overgrowth around a wound or canker.

Canker. A dead, sometimes sunken or cracked area surrounded by living tissues on a stem.

Caterpillar. The "worm-like" stage (larva) of a moth or butterfly.

Cephalothorax. The fused head and thorax found in forms such as spiders and lobsters.

Cerci. Slender, paired and segmented appendages arising from the tenth abdominal segment of some insects.

Chemotherapy. Cure or prevention of disease in plants by internal chemical treatments.

Chitin. The outer coating of an insect formed by cells that secrete a semi-liquid substance which solidifies on exposure to air.

Chlamydospore. A thick-walled, asexual resting spore.

Chlorosis. Yellowing of normally green tissues because of the partial failure of chlorophyll to develop.

Cocoon. A protective sac, spun by the larvae of many insects, in which they pass the pupal stage.

Compatible. Refers to chemical materials that can be mixed together without changing their effects adversely on pests or plants.

Conidia. Asexual spores produced on conidiophores other than sporangiospores and chlamydospores.

Conidiophore. Simple or branched hypha on which conidia are produced.

Contact poison. A chemical that kills when it contacts some external part of a pest.

Control. Prevention of, or reduction of, losses from pests by any method.

Cornicles. Two tubes on the upper posterior end of the abdomens of aphids, which secrete a waxy liquid.

Coxa (pl. *coxae*). The basal segment of an insect's leg.

Damping-off. Seed decay in the soil or the decay of the bases of seedlings.

Diagnosis. Identification of the nature and cause of a plant trouble.

Die-back. Progressive death of twigs or leaves beginning at tips.

Diluent. Any liquid or powdered material that is used to reduce the concentration of a chemical for spraying or dusting purposes.

Dioecious. Plants that have only staminate or pistillate flowers on one plant.

Disease. Any change in a plant that affects its normal structure, functions, or economic value.

Disinfectant. An agent that frees a diseased plant or any of its parts from infection.

Disinfestant. An agent that kills or inactivates organisms before they attack plants, as in the soil or on seed surfaces.

Dissemination. The transport of inoculum or pest from a diseased to a healthy plant.

Dorsal. Referring to the back or upper side of an organism.

Elytra (sing. *elytron*). The hard, upper wings of beetles.

Emulsifiable liquid. A liquid that will form an emulsion when it is mixed with water.

Emulsion. A dispersion of one liquid in another in the form of tiny droplets.

Enphytotic. The sudden and destructive development of a plant disease, usually over large areas (adjective form: epiphytotic).

Estivation. The period of suspended animation in many tropical insects and in some animals in response to hot, dry condtions.

Etiolation. Excessive spindliness in plants, owing to lack of sufficient light or disease.

Etiology. Study of the cause of disease.

Exudate. Liquid discharge from diseased or injured tissues.

Facets. The visual units that compose a compound eye.

Femur (pl. *femora*). The third and usually the heaviest segment of an insect's leg, counting from the body.

Form. The resting place of a rabbit or hare.

Frass. The wet or dry sawdust-like excrement of borers, usually evident at their exit holes in fruits and other plant parts.

Fruiting body. A fungous structure that contains or bears spores.

Fumigant. Any material that when in the form of a gas or vapor destroys organisms.

Fungicide. Any agent that kills or inhibits fungi (or, when used in a broad sense, bacteria).

Fungus (pl. *fungi*). A plant without chlorophyll, usually possessing a thread-like body and reproducing by means of sexual or asexual spores.

Gall. A more-or-less spherical outgrowth of unorganized plant cells produced by the irritation of bacteria, fungi, mites, or insects.

Generation. Referring to a group of progeny originating from adults of a preceding group.

Germ tube. The hyphal thread produced by a germinating fungous spore.

Gestation period. The period of embryonic development in mammals.

Gradual metamorphosis. The growth changes in insects from newly hatched nymphs to adults.

Gram-negative. Not capable of being stained by the standard Gram stain.

Gram-positive. Capable of being stained by the standard Gram stain.

Grub. The larva of a beetle.

Halteres. Short-knobbed appendages present in place of the hind wings of true flies.

Haustorium (pl. haustoria). A specialized food-absorbing organ that grows into a cell from the hyphae of certain species of fungi.

Hemelytra (sing. hemelytron). The top pair of wings of true bugs, which have their basal ends thickened and their distal ends membranous.

Herbaceous. Referring to plants with soft stems, such as annuals, biennials, and perennials that normally die back to the ground in the winter.

Herbicide. Any agent or chemical used in the destruction or control of weeds.

Heteroecious. Requiring two or more unrelated hosts for completing the life cycle.

Hibernation. The period of suspended animation in insects and in some higher animals in response to seasonal low temperatures.

Host. Any plant or animal attacked by a parasite or a predator.

Hyperplastic. Refers to type of symptom characterized by the abnormal multiplication of cells.

Hypha (pl. hyphae). A single thread of fungous mycelium.

Hypoplastic. Refers to type of symptom characterized by the underdevelopment of cells, tissues, or organs.

Immune. Not subject to attack or infection by a given organism.

Incomplete metamorphosis. Similar to gradual metamorphosis but generally used to denote the growth changes of naiads.

Incubation stage or period. The period beginning when inoculation occurs and ending when symptoms of disease can first be observed. In birds, the period of embryonic development within the egg.

Infection court. Any place where an infection may take place.

Infection stage. The period during which the disease-producing organism causes symptoms of disease to appear in a plant.

Inoculation Stage. The period during which inoculum is being transferred from its source to the infection court.

Inoculum. Spores or any part of a pathogene that can infect plants.

Insectivorous. Feeding on insects.

Intercellular. Between cells.

Intracellular. Within cells.

Invertebrates. Animals that have no backbones, such as insects, slugs, spiders, etc.

Larva (pl. larvae). The growing, worm-like stage of insects with a complete metamorphosis. Also, the newly hatched six-legged stage of mites and ticks.

Lesion. Any break in the epidermis of a plant; a localized, diseased area.

Lethal. Deadly.

Life cycle, life history. The complete succession of events in the life of an organism.

Maggot. The growing stage or larva of a fly.

Mandibles. The heavy pair of biting or chewing organs in an insect's mouth.

Mesothorax. The middle section of the thorax of an insect that bears the top wings and the middle pair of legs.

Metamorphosis. Any conspicuous changes in form or structure during the growth of animals.

Metathorax. The last division of the thorax of insects, bearing the second pair of wings and the third pair of legs.

Micron. A unit of measurement equal to one one-thousanth of a millimeter.

Mildew. A fungous disease characterized by the appearance of a white, mycelial growth and spores on the surface of infected plant parts.

Mold. A fungus with conspicuous mycelium or spore masses.

Molt. The shedding of the skin of insects and snakes in the process of growth, or of the feathers of birds and the fur of mammals.

Monoecious. Refers to plants that have separate staminate and pistillate flowers on the same plant; also to rusts that have all stages of their life cycle on a single species of plant.

Mosaic disease. One characterized by variegated patterns of green and yellow on the foliage of plants affected by certain viruses.

Mycelium. A mass of hyphae that forms the body of a fungus.

Naiad. The aquatic growing stage of insects with an incomplete metamorphosis.

Necrotic. Having symptoms characterized by the death or disintegration of cells or tissues.

Nematode worms, nemas. Microscopic roundworms, many of which attack plants.

Nestling birds. Newly hatched birds that are confined to their nests.

Non-infectious disease. A disease that cannot be transmitted from one plant to another; a disease caused by a physiopath.

Non-septate. Without cross-walls.

Nymph. The growing stage of insects with a gradual metamorphosis.

Ocelli. Small, single visual units located on the heads of spiders and many insects.

Oesophagus. The part of the alimentary canal that connects the mouth with the intestinal tract.

Oöspore. A resting spore produced by sexual reproduction in the downy mildew and related fungi.

Ovicide. Any factor or chemical that destroys eggs.

Oviparous. Reproducing from eggs laid by an animal.

Ovipositor. An organ, present in many insects, specialized for depositing eggs in plant structures or in the ground.

Ovoviviparous. Reproducing living young from eggs that hatch within the female's body.

Parasite. Any organism that lives on or in the body of another organism and obtains nourishment from it.

Parthenogenesis. The reproduction of young from unfertilized eggs.

Pathogene. Any organism or factor that is capable of causing disease.

Pathogenesis. The period during which the pathogene is actively attacking the living tissues of its host.

Perithecium (pl. *perithecia*). The flask-like, fruiting body of a fungus, containing asci, usually the overwintering stage of certain fungi such as the one causing apple scab.

Pest. Any organism injuring plants or plant products.

Physiogenic Disease. A disease produced by a physical or an environmental factor.

Physiopath. Any physical or environmental factor capable of producing symptoms of disease in plants.

Poison bait. A substance that has a poison mixed with it that is attractive as a food for certain animals.

Predator. An animal (insect included) that attacks and kills another animal in order to obtain food.

Prolegs. The fleshy, unsegmented leg-like structures on the abdomens of some larvae.

Prothorax. The first segment of the thorax, which bears the first pair of legs.

Pupa (pl. *pupae*). The stage during which an insect with complete metamorphosis is transforming from the larval to the adult stage.

Puparium (pl. *puparia*). The darkened and hardened last larval skin of a maggot, which protects the pupa of true flies.

Pycnidium (pl. *pycnidia*). Flask-like fruiting body containing conidia.

Race or strain. Organisms of the same species and variety that differ in their ability to produce disease in varieties of a given host or that differ in their reaction to insecticides or fungicides.

Resistant. The ability of a host to suppress or retard the injurious effects of an organism.

Rhizome. An underground stem that sends up new shoots.

Rodenticides. Chemicals used to destroy rodents and related animals.

Roguing. The removal of undesired individual plants from a group of plants.

Russetting. Brownish roughening on the skins of fruits as a result of disease or injury.

Saprogenesis. The period in the life cycle of a pathogene when it is not associated with living tissues of its host. This may include a period of dormancy.

Segmented. Divided into distinct divisions.

Selective herbicide. One that destroys certain species of plants or weeds and leaves others relatively unharmed.

Septate. Possessing cross-walls.

Sign. Evidence of disease as indicated by the presence of the disease-producing organisms or of any of their parts or products.

Slurry. A thick suspension of a finely divided substance in a liquid.

Species. One kind of plant or animal. Abbreviated as sp. singular and spp. plural. Spp. following genus name means that a number of species of that genus are indicated.

Spinneret. Organs found in certain insect larvae and in spiders, which are used in spinning silken threads.

Spiracles. The external openings to the breathing organs of insects and related forms.

Spore. A single-to-many-celled body capable of reproducing the fungus or other lower plant from which it originated.

Sterilant. Any agent or chemical that destroys all living organisms in a substance or renders it barren.

Stolon. A creeping stem that sends down roots and produces new shoots.

Stomach poison. A poison that takes effect when swallowed.

Stomata (sing. stoma). Minute pores present in the leaves of plants, utilized in the exchange of gases for respiration and photosynthesis.

Strain, see Race

Stylets. The hair-like piercing and sucking organs possessed by insects that feed on the sap of plants.

Subspecies. Groups in an animal species that differ from each other in certain minor details usually because of geographical location.

Suscept. A more precise term for host—any plant liable to infection by a given organism.

Symptoms. Evidence of disease in plants expressed by the reaction of the plants to the presence of the irritating factor or organism.

Synergist. Any substance that increases the toxic effects of a pest-control chemical.

Synthetic. Compounded in the laboratory, as opposed to occurring naturally.

Systemic disease. One in which the pathogene spreads throughout the plant body.

Tarsus (pl. *tarsi*). The jointed "foot" that bears the claws of an insect.

Thorax. That portion of an insect's body which lies between the head and abdomen and bears the legs and wings.

Tibia (pl. *tibiae*). The long, slim segment of an insect's leg to which the tarsus is attached.

Tolerance. Amount of toxic residue allowable on or in edible substances under the law.

Toxic. Poisonous.

Toxin. Poison produced by an organism.

Tracheae. The larger respiratory tubes leading from the spiracles.

Trade name. Name given to a product sold by a company to distinguish it from similar products made by other companies.

Translocated herbicide. One that enters plant foliage and is carried to other parts of the plant killing or affecting parts to which the chemical is not directly applied.

Unsulfonated residue. A measure of the saturated hydrocarbons in an oil that does not react or combine with sulfuric acid.

Varieties. Plants in a species that differ from each other in certain details such as form, color, fruit size, fruit flavor, etc.

Vascular. Refers to conducting tissues (phloem, xylem) of plants.

Vector. Any carrier of a disease-producing organism.

Ventral. Referring to the underside of an organism.

Viability. State of being alive.

Virulent. Strong ability to produce disease.

Viviparous. Reproducing living young that undergo embryonic development in the abdominal cavity of the female.

Wettable Powder. One that is easily wetted by water and will go into suspension.

Zoöspore. Spore capable of independent movement in water; a swarmspore.

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